All you can heat? Welfare implications of high fixed charge tariffs for electricity.

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Abstract

This research investigates the implications of residential electricity tariffs with high daily fixed charge or fixed-like components, like 'all you can eat' or 'uncapped' tariffs which are common for access to internet services. The objective and contributions of the research are: to improve the state of knowledge about household electricity demand in New Zealand; estimate household expenditure systems using methods that are novel in New Zealand; and to provide evidence on tariffs that are likely to be welfare improving. Models of household expenditure are estimated and they show household electricity demand to be highly responsive to changes in average electricity prices, in contradiction of conventional wisdom that electricity demand is price inelastic. A counterfactual price experiment shows a substantial gain in efficiency and an improvement in social welfare from electricity tariffs with high fixed charge components as opposed to the status quo where high variable charges act as a tax on electricity consumption. High fixed charges are shown to be progressive, contradicting concerns that high fixed charges would exacerbate inequality. Smaller households, typically older households, would likely be worse off from high fixed charges, but not substantially or universally so.

Disclaimer

Access to the data used in this study was provided by Statistics New Zealand under conditions designed to give effect to the security and confidentiality provisions of the Statistics Act 1975. The results presented in this study are the work of the author, not Statistics NZ.

The results in this thesis are not official statistics They have been created for research purposes from the Integrated Data Infrastructure (IDI), managed by Statistics New Zealand.

The opinions, findings, recommendations, and conclusions expressed in this thesis are those of the author, not Statistics NZ.

Access to the anonymised data used in this study was provided by Statistics NZ under the security and confidentiality provisions of the Statistics Act 1975. Only people authorised by the Statistics Act 1975 are allowed to see data about a particular person, household, business, or organisation, and the results in this thesis have been confidentialised to protect these groups from identification and to keep their data safe.

Careful consideration has been given to the privacy, security, and confidentiality issues associated with using administrative and survey data in the IDI. Further detail can be found in the Privacy impact assessment for the Integrated Data Infrastructure available from www.stats.govt.nz.

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Chapter 1

Introduction

1.1 Objective

The primary objective of this research is to test the hypothesis that high fixed charges for electricity would reduce social welfare or increase inequality.

Residential electricity pricing in New Zealand fails basic economic tests of efficiency. Households' electricity bills are dominated by charges based on the amount of electricity consumed. Yet a large proportion of the costs of electricity systems do not vary according to energy consumption. This means that prices are signalling costs that cannot be avoided and people are needlessly economising on electricity use.

This issue arises because of the way that electricity network costs are recovered. Electricity prices consist of three general components: energy generation costs, energy transportation and network costs, and retail or customer-service costs. Transportation and network costs are large and generally fixed and sunk.

Networks are regulated by the Commerce Commission precisely because their large fixed costs, or increasing returns to scale, constrain competition. Yet a large proportion of these fixed network costs are recovered using variable prices based on amounts of electricity consumed so that consumers' are encouraged to reduce their use of networks even when reduced use has no effect on the costs to be recovered.

A simple solution to this problem would be for retail electricity tariffs to include higher fixed charges, to recover fixed network costs, and lower variable (cents per kWh) prices so as not to discourage electricity consumption. High fixed charges are not uncommon in other network industries such as telecommunications where consumers can choose price options with single fixed price for any level of use.

'All you can heat' tariffs for residential electricity use would need to include some degree of variable pricing, given comparatively high variable costs in electricity supply relative to other network industries. However fixed charges could be multiples of current levels without compromising the efficiency criteria that prices should reflect marginal costs.

However, this sort of change to electricity pricing would be met with resistance from those who benefit from low fixed charges. In 2019 the New Zealand Government considered a review of low fixed charge regulations. In response the lobby group Grey Power submitted that "the low fixed charge tariff if phased out will exacerbate energy hardship".[1]

The focus here is on welfare broadly defined in terms of market incomes and expenditure, rather than energy use. This view of welfare admits logically consistent analysis of distributional consequences, to see if higher fixed charges will cause an increase in inequality.

The scope is restricted household electricity consumption, ignoring industrial and commercial use of electricity. Household demand accounts for 32 percent of electricity consumption[2] in New Zealand and 40 percent of expenditure on electricity.[3]

[1]Grey Power submission to the 2019 Electricity Price Review, available at https://www.mbie.govt.nz/dmsdocument/4863-grey-power-nz-federation-inc-submission-electricity-price-review-options-paper-pdf, accessed 11 December 2020

[2]MBIE electricity statistics, 2019. Household shares of electricity consumption have been very stable in the past decade and half, averaging 32 percent with a standard deviation of 0.6 percent

[3]Households have a higher expenditure share than consumption share because households consume the full range of electricity and electricity-related services - from wholesale energy and transmission services to distribution network, and retail and risk management services - and are more likely to consume when electricity capacity costs are highest (when demand is at its peak). The estimate of household expenditure share presented here is a March year 2018 estimate based on an estimated total market size of 7.7 billion dollars, inclusive of network costs and wholesale electricity costs. The total market size is the sum of networks revenues disclosed to the Commerce Commission plus wholesale market energy costs published by the Electricity Authority and retail market margins based on MBIE's quarterly survey of domestic electricity prices. Household expenditure is estimated to be 3.1 billion

The focus on households allows for a single framework for evaluating welfare effects and helps to fill a gap in analyses of electricity pricing in New Zealand which, to date, have not included rigorous analysis of the welfare or distributional implications of high fixed charges.

The framework used for evaluating welfare effects does not address questions of dynamic efficiency or investment effects. While this is a short coming, those issues are much larger than could be taken up here.

A subsidiary objective of this research is to improve the state of knowledge of demand analysis, both in terms of electricity demand and estimation of demand systems. With respect to electricity demand, there is relatively little publicly available research that investigates household-level responses to changes in electricity demand in New Zealand.

1.2 Context

At an aggregate level, residential demand for electricity has grown very little over recent years and rising network costs and increasing prices are leading candidates for explaining why demand has not increased.

Electricity is much more expensive now that it was fifteen years ago. Between 2006 and 2015 average unit costs for residential electricity increased 24 percent; a compound annual average growth rate of 2.4 percent growth each year over and above general consumer price inflation. Since 2015 average unit costs have been flat to declining but they remain 18 percent higher in 2020 than in 2006.

Over the same period, average annual household consumption of electricity has declined from 7,630 kWh in 2006 to 7099 in 2020, a 6 percent decline (see Figure 1.1).[4] Total residential electricity consumption increased by only 0.2 percent between 2006 and the end of 2019 while the number of residential electricity network connections increasing by 9.3 percent[5] and average real household disposable income increased by

dollars based on MBIE's quarterly sales-based electricity costs.

[4]MBIE quarterly sales-based electricity costs.

[5]Data is for calendar years 2006 to 2019, from MBIE's electricity statistics.

33 percent between June 2006 and June 2019.[6]

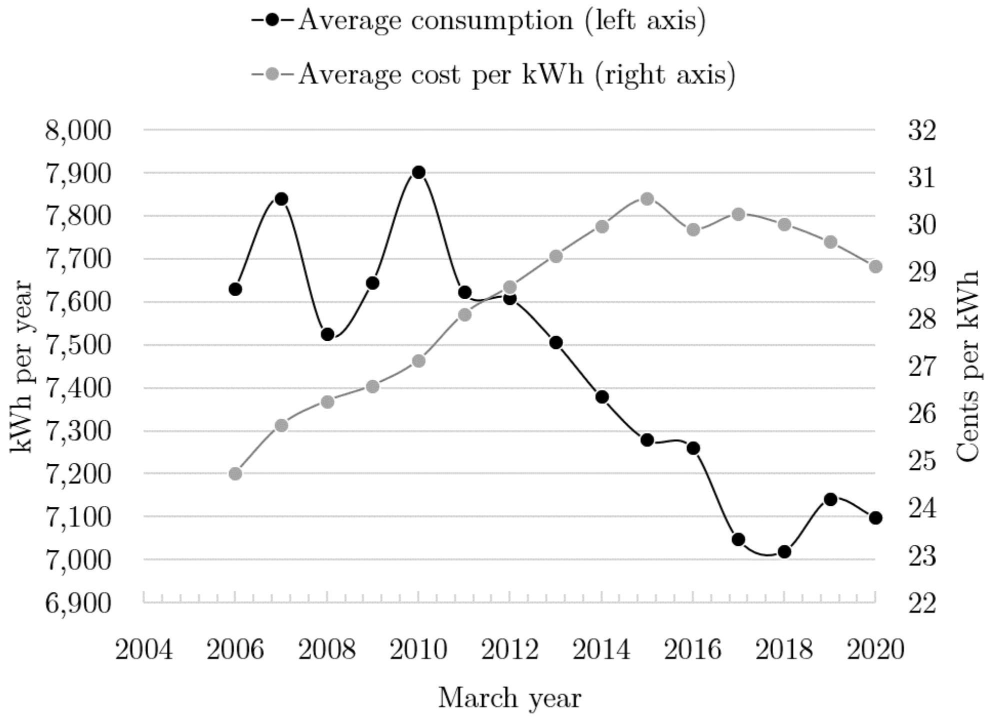

Figure 1.1: Average residential electricity consumption and inflation-adjusted costs (2020), MBIE quarterly residential sales-based electricity cost.

The leading cause of increased electricity prices has been increases in transmission and distribution charges (see lines costs in Figure 1.2). Between 2006 and 2020 62 percent of the increase in average inflation-adjusted electricity prices was due to increased lines costs.

Electricity prices have declined in the past three years (from 2018 to 2020), largely because of a reduction in the regulated rate of return on network companies' assets. However, the rise in lines charges that occurred prior to 2018 will persist for some time because it reflects a substantial increase in the size of the regulated asset base upon which lines charges are set.

There is no way to recover the costs of fixed network costs without distorting use of electricity and of electricity networks(Borenstein, 2016). Numerous methods have been proposed over the years, including funding networks' capital costs through general

[6]Stats NZ Household income and housing-cost statistics, February 2020, income figures deflated by the CPI

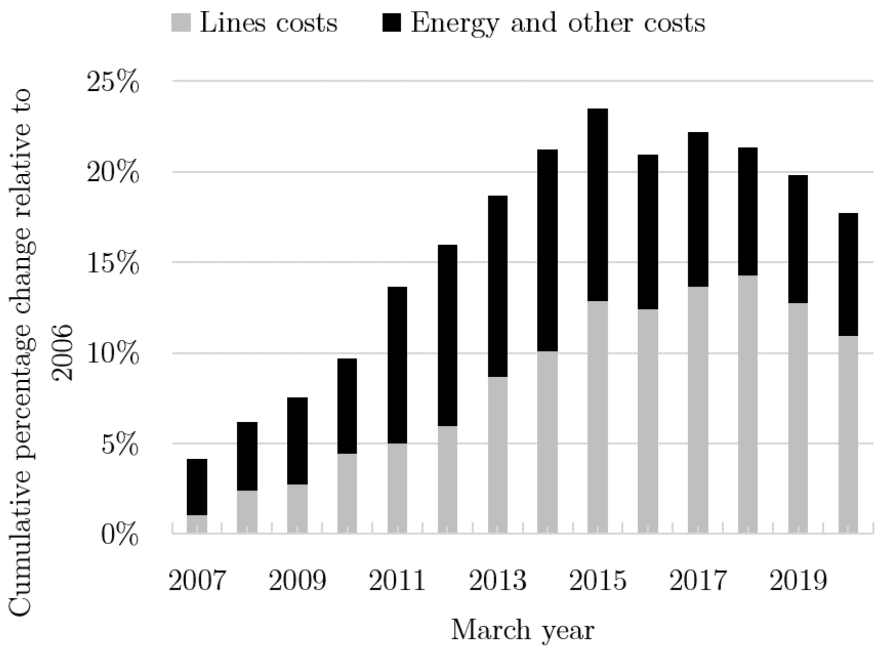

Figure 1.2: Contributions to inflation-adjusted energy cost increases, MBIE quarterly residential sales-based electricity cost.

taxation (Hotelling, 1938) and using two-part tariffs that include a fixed charge per network user to recover network's sunk capital costs (Coase, 1946; Feldstein, 1972).

The one thing that proposed solutions have in common is that costs should be recovered in a least distortionary way. The main area of disagreement is over what least distortionary means. For example, funding capital costs through general taxation removes distortions to electricity use but replaces them with distortions to production or labour supply and incentivises inefficient investment by removing the feedback loops that user-pays provides between levels of fixed costs and consumer willingness to pay (Coase, 1970). Similarly, concern for long-run efficiency of investment, over short-run consumer demand distortions, give rise to the view that, in practice, least distortive electricity tariffs should signal future investment costs (long-run marginal costs) (Kahn, 1988, p. 108).[7]

This problem of recovering sunk costs is analagous to questions of optimal taxation, where the objective is to raise revenue while minimising dead-weight losses from dis-

[7]Setting aside the overall efficiency of these sorts of prices, which is questionable (Borenstein, 2016), long-run marginal cost pricing is only a partial solution to the question of least distortionary cost recovery because such charges will not fully recover a network's capital costs.

torting labour supply or consumption decisions. Indeed, a frequently cited method for sunk cost recovery from network industries relies on a famous result from the optimal taxation literature which suggests recovering costs from consumers using a mark-up, over variable costs, that is inversely proportional to distortions created by the mark-up; known as Ramsey-Boiteux pricing after Frank Ramsey who formulated conditions under which revenue collection is least distortive, in the context of taxation, and Marcel Boiteux who used the same reasoning to formulate efficient pricing for revenue recovery for natural monopolies subject to a budget constraint (Ramsey, 1927; Boiteux, 1956; Wilson, 1993, p. 98).

Like many tax theories, Ramsey-Boiteux pricing suffers from information and political-economy problems (Laffont and Tirole, 1993, p. 32). It is difficult and costly to collect the information needed to identify how consumers will respond to price mark-ups. Even if the necessary information can be obtained, or an approximation to it, differentiated prices raise incentives on people to lobby government, firms or regulators for alternative allocations or for transfers. Ramsey-Boiteux pricing also has political and socially unpalatable distributional implications because, when it comes to necessities, the least well-off consumers are likely to have highly inelastic demand and thus face above average charges.

Distributional consequences ought not to matter if transfers can be provided to meet distributional objectives. Wilson (1993) provides a useful summary of arguments in favour of choosing allocatively efficient prices rather than trying to pursue distributional objectives:

> ...each customer is affected by utilities in several industries and by an assortment of public programs, as well as taxes, subsidies and welfare programs with substantial distributive effects. Absent a coherent scheme to coordinate all these programs to achieve distributive objectives, if each program maximizes total benefits then in aggregate the greatest potential benefit is available for redistribution via taxation and other programs with explicit welfare or distributional objectives. (p.101)

But distributional objectives and other factors unrelated to efficiency are important considerations in political and policy decision-making. For example, the scope of the New Zealand Government's electricity price review, concluded in 2019, included equity and fairness.[8] This suggests that analyses of the efficiency of pricing regimes needs to be accompanied by an assessment of distributional consequences much as they are in tax analysis.

In recent years, there has been renewed interest in network pricing, prompted by emerging technologies that are changing the ways that energy and electricity networks are used. There is concern that problems with conventional pricing will be magnified by new technologies. For example, studies here and overseas have shown that conventional electricity pricing practices can cause people to over-invest in solar photovoltaics (Electricity Authority, 2018; Borenstein, 2017) in the sense that reductions in electricity bills of households with solar are out-of-proportion to economic cost reductions. This risks a situation of aggregate inefficiency where increased investment in solar causes an increase in total system costs of supply but electricity consumption is unchanged.

Furthermore, under consumption-based cost-recovery, if consumption of electricity on regulated networks declines then firms' revenues decline. If this decline in revenue is not matched by declining costs, profitability comes under pressure and with it incentives to invest in or maintain networks and service quality. If networks raise their prices this only further increases incentives to invest in solar (Brown and Sappington, 2018).

These dynamics could have regressive distributional consequences. If only higher income households can afford to install solar systems, then lower income households could face increasing electricity costs as increasing numbers of higher income households install solar systems.

Electricity pricing can also undermine other policy objectives by inhibiting uptake of new technologies. For example, electricity prices that are largely based on consumption of electricity will tend to overstate the costs of charging electric vehicles outside of demand peaks and hence discourage the uptake of a potentially important means of mitigating emissions of carbon dioxide.

At the same time, charging of electric vehicle batteries during peak demand periods could cause a significant increase in electricity networks' capital costs, to augment their networks to accommodate this demand. [9] This too introduces equity concerns in so

[8] https://www.mbie.govt.nz/dmsdocument/3762-terms-of-reference-electricity-price-review-pdf

[9] A large amount of the literature on utility pricing focusses on the problem of peak-load pricing and efficiency of investment. This is the problem associated with pricing system capacity that is used only infrequently, during periods of peak demand (Crew, Fernando, and Kleindorfer, 1995). This an

far as any network costs creating from electric-vehicle charging will be shared by all network users while, at least in the short term, the benefits of electric vehicle charging are more likely to accrue to higher income households.

In New Zealand, network owners have been engaging with these issues (ENA, 2017). However the focus of price reform has been on creating price signals that will assist with cost control by incentivising consumption of electricity outside peak demand periods. Comparatively little attention has been paid to reducing reliance on consumption based charges for recovery of sunk costs.

Borenstein (2016) has argued that higher fixed charges are the most promising option for avoiding some of these problems while ensuring that network owners recover the costs of their investments. He notes, however, the problem that higher fixed charges are often considered inequitable. This presents a barrier to reform.

In New Zealand, Government policy has been a direct barrier to higher fixed charges in electricity tariffs. New Zealand's low fixed charge regulations limit the size of fixed charges in residential electricity tariffs.[10] Under the regulations retail tariffs must include a low fixed charge (LFC) option which is a tariff with a fixed fee no higher than 30 cents per day excluding GST.[11] Tariffs with higher fixed fees must have a counterpart LFC option that is equivalent in the sense that a household consuming 8,000 kWh per year would face the same annual electricity bill under either tariff.[12]

The regulations "were introduced in 2004 to provide low-use consumers with a tariff option that is more equitable for low energy usage and compatible with the Government's energy-efficiency objectives".[13]

The presumption was that low fixed tariff options would promote energy efficiency, because they had the effect of reducing prices for people who reduced their consumption below a certain level. It is unclear if government considered the effect that lower average

issue that is closely related to the question of fixed cost recovery, however peak-load pricing is not the focus here and the intricacies of these issues are not discussed further.

[10] Electricity (Low Fixed Charge Tariff Option for Domestic Consumers) Regulations 2004.

[11] The 30 cent price limit was established with the regulations in 2004 and has not been revised since

[12] For households south of Arthur's Pass the basis for establishing tariff equivalence is 9,000 kWh

[13] Hansard, Hon Darren Hughes Deputy Leader of the House on behalf of the Minister of Energy (19 March 2008), available at: `http://www.parliament.nz/en-nz/pb/debates/debates/speeches/48HansS_20080319_00001656/hughes-darren-electricity-disconnection-and-low-fixed`

prices for small households might have on increasing their energy consumption. It also unclear whether the Government considered that any reduction in consumption would be an efficiency gain regardless of the associated costs incurred or if the Government had specific forms of energy efficiency in mind when enacting the low fixed charge regulations.

The effects of the LFC regulations have been to raise the average bills of households that use a comparatively large amount of electricity and reduce the average bills of households that use comparatively small amounts of electricity. These effects are similar to those of increasing block tariffs used elsewhere in the world to try and improve the affordability of electricity for low income households. However the link between household consumption of electricity and household income is tenuous and consequently regulations that raise prices for higher levels of consumption can have negative consequences for consumer welfare and potentially for inequality (Feldstein, 1972; Borenstein and Davis, 2012; Borenstein, 2016). Of course, higher fixed charges have the reverse effect on prices, such that average electricity costs are highest for those that consume comparatively little. This then raises questions about whether higher fixed charges would be worse than the status quo.

The extent to which high, or at least higher, fixed charges are efficient or welfare improving depends on how consumers respond to electricity prices. This is, at least partly, an empirical matter. Thus the main contribution of this research is to investigate, empirically, whether higher fixed charges might be a beneficial alternative to the status quo of high variable consumption (kWh) prices. That is, to test the hypothesis that high fixed charges would reduce consumer welfare or increase inequality.

Empirical research from elsewhere in the world points to potentially positive effects from higher fixed charges, but emphasises that there will be winners and losers and potentially negative distributional consequences. For example, Gomez-Lobo (1996) found that a change in tariff structures in the retail residential gas market in the United Kingdom, towards more cost reflective tariffs and a higher fixed charge, would result in overall welfare gains but welfare losses amongst households in the lowest quintile of income.

Borenstein (2012) finds, with simulation analysis, that increasing block tariffs in California caused dead-weight (efficiency) losses, from reduced electricity consumption, that are out of proportion to the modest amount of redistribution provided by tariffs predicated on a positive relationship between electricity consumption and income or wealth. The article concludes that targeted subsidies are more cost-effective. It also notes that analysis of the redistributive effects of tariffs requires data that can account for the significant heterogeneity in electricity use by low income households, while limitations on access to such data means that analysis is often based on averages over geographical areas such as census blocks.

Borenstein and Davis (2012) analyse the efficiency and distributional effects of increasing the fixed component of gas tariffs in the United States. They find that cost reflective two-part tariffs with high fixed charges are regressive, relative to the status quo. But they also find that the status quo is not a cost-effective redistributive mechanism. Under an assumption that consumers respond to marginal prices, when choosing consumption levels, they find that efficiency (consumer surplus) losses from tariffs with low fixed charges and high volume charges are 20 percent larger than the amount of wealth redistributed to lower income households. They consider the extent to which increased fixed charges could cause a welfare loss due to a net reduction in the number of gas connections (increase in people disconnecting or decrease in connections) and conclude that this is unlikely but that that their finding of efficiency gains relies on their being no significant net change in connections.

Price and Hancock (1998) considered the cumulative effect that changes to tariff structures of for gas, electricity, water and telecommunications would have on low-income and elderly households in the United Kingdom. During the 1990s many countries, including the United Kingdom, embarked on substantial reform of their utility industries with an expectation that exposing parts of these industries to the discipline of competition would reduce prices to consumers. However, reforms also led to a widespread rebalancing of tariffs towards volume discounts that promoted consumption. This had the effect that costs increased for households with low levels of expenditure and those households included large numbers of low income households and retirees.

There is no equivalent research in New Zealand considering changes in energy prices. However, there is research into the effects of indirect taxation on household welfare that is comparable to research in other countries on the effects of changes to energy prices. For example Creedy and Sleeman (2005b) found that elimination of excise taxes would both improve the efficiency of the tax system and reduce income inequality, though there would be winners and losers with the largest gains accruing to smoking households because of the high excise taxes on tobacco products. Creedy (2004) simulated the effects of a petrol excise increase on welfare and on inequality and found that an excise increase would increase inequality, by a small amount.

Ball, Creedy, and Ryan (2016) is the New Zealand study most similar to international research into the rebalancing of energy prices. The article examined the efficiency and distributional consequences of exempting food from goods and services tax (GST), with and without revenue neutral changes to GST rates. They found that, with revenue neutrality enforced, lower income households benefit because of their higher average expenditure shares on food while higher income households bear the balance of costs from higher GST rates. However, they also find substantial redistribution from smaller households, with lower expenditure shares on food, to larger households and households with children who have higher expenditure shares on food. They also find that targeted transfers would be a more efficient way to achieve redistributive objectives that underpin interest in exempting food from GST.

International empirical research on the consequences of tariff reform emphasises the interaction between conceptually optimal pricing and consumer behaviour which deviates from theoretically optimal behaviour. Ito (2014) investigated the welfare consequences of flat rate (cents per kWh) tariffs against tiered tariffs where the marginal price increases with higher consumption, similar in effect to the LFC regulations in New Zealand except that the price changes increase in discrete steps. He finds that, in general, a flat rate tariff is welfare improving. However he also finds that demand does not cluster around the discrete price steps as one might expect if households are responding to marginal price changes. Thus he concludes that that households in California respond to average rather than marginal electricity prices and notes that this has implications for the efficiency of marginal cost pricing in practice. The study is based on a robust quasi-experimental methodology and detailed unit-record data set. This supports some degree of departure from strict adherence to models of consumer optimisation at the margin, or at least a redefinition of the relevant margin of decision making in the context of rational inattention.

A similarly robust quasi-experimental analysis by Shaffer (2020), analysing effects of network pricing reforms in British Columbia, found evidence that consumers made decisions based on average prices. The study also found evidence that some households misunderstood marginal prices and acted as if marginal prices were average prices. This created significant welfare costs for this portion of households that misunderstood prices.

Findings from other countries may not transfer perfectly to New Zealand because, for example, New Zealand electricity prices are less complicated than the increasing-block tariffs studied by Ito. However, the observation that consumers often respond to average instead of marginal prices is a phenomenon with strong empirical support in other contexts such as tax rates (Rees-Jones and Taubinsky, 2020).

A further issue of behavioural complexity that is canvassed in the literature is the role of framing in affecting the political or social acceptability of tariff reform. This issue is not taken up in this thesis, but it is an important limiting factor in the usefulness of empirical analysis. Changes to tariffs can appear, to the analyst, to be welfare improving yet cultural norms and people's perceptions affect how people react to tariffs and people's preferences over tariffs. This adds an additional layer of complexity when considering tariff reform.

For example, an experimental survey in Australia has suggested that consumers there generally favour simple flat-rate or consumption-based tariffs and dislike tariffs that reflect higher costs of energy at times of peak demand (Stenner, Frederiks, Hobman, and Meikle, 2015), even if cost-reflective charges are more efficient. Notably, the Australian study did not investigate reactions to high fixed charges.

Policy interventions can also shape consumer behaviour by altering in the context in which consumers make decisions, causing consumer decision making to depart significantly from conventional models of marginal decision-making. For example, Beatty, Blow, Crossley, and O'Dea (2014) found that a winter energy payment in the United Kingdom led to an increase in spending on energy that was substantially higher than would be predicted by marginal expenditure on energy. The payment was a cash transfer provided to people aged over sixty-five. Nearly half of this cash transfer was spent on energy - more than ten-times larger than energy expenditure elasticities would have suggested. The authors suggest that this is strong evidence of a labelling effect, whereby consumer spending decisions are influenced by the name given to the transfer payment.[14]

[14]New Zealand introduced a similar scheme in 2019 with cash transfers available to all people over sixty-five and all other recipients of government income support.

1.3 Methodology

This research is primarily empirical and relies heavily on modelling of almost ideal demand systems (Deaton and Muellbauer, 1980; Banks, Blundell, and Lewbel, 1997) fitted to micro-data on household expenditure and incomes from the New Zealand Household Economic Survey. Chapter 2 presents the theoretical details of these models and details of the estimation methods used. Chapter 3 discusses the data used to estimate the models.

The focus is on establishing a baseline relationship between household consumption decisions and electricity prices and then to evaluate counterfactual changes in household demand and welfare from changes in prices.

Demand systems provide a logically and theoretically consistent way to establish the responsiveness of households to changes in electricity prices, conditional on the prices of other products and household incomes and household size.

Demand systems based on household level data suffer less from identification problems and simultaneity bias than do other analyses, especially aggregate estimation of market price elasticities. Identification problems and simultaneity bias confound most estimates of price elasticities of demand based on aggregated data. This is especially so for electricity where, traditionally, declining average costs of production and adjustment costs manifest in investment cycles. With fixed capacity in any given year, an unanticipated increase in demand can cause prices to rise, leading to a downward bias in estimated price elasticities or even positive price elasticities.

This choice of methodology is also based on the relative novelty of using demand systems to analyse electricity demand, thus providing a complementary perspective to other empirical analyses. Furthermore the choice has been made to use almost ideal demand systems, including the quadratic form of the model, because these methods are used much less frequently in New Zealand than other demand systems such as the linear expenditure system (as discussed in section 2.1).

Publicly available research in New Zealand into residential electricity price elasticities of demand are almost entirely aggregate demand elasticities. The only exception is Thorsnes, Williams, and Lawson (2012), which is an experimental analysis of responses to time of use pricing.

New Zealand is not alone in its relative paucity of micro-level analyses of household electricity demand. A recent meta-analysis of residential electricity demand elasticities by Zhu, Li, Zhou, Zhang, and Yang (2018) illustrates the widespread use of high level, typically time series, analysis of demand elasticities. While these types of analyses can be useful descriptions of aggregate data generation processes, they have questionable value in terms of structural analysis and for investigating welfare effects.

The decision to estimate theoretically consistent almost ideal demand systems does impose a cost in terms of more demanding estimation techniques (such as with non-linear system estimation) and higher resource costs in terms of data acquisition.

It is perhaps because of these costs that empirical applications of demand systems typically fail to present sensitivity tests of their model specifications, or tests of theoretical restrictions used when estimating their models. In some cases they do not even present model parameter estimates (see Thomas (2019) and discussion in section 2.1).

Here the methodology includes testing of alternative model specifications, both in terms of high level form of the model to be estimated and in terms of the choice of exogenous variables. The results of these alternative specifications are discussed in Chapter 4 which presents the results of the empirical estimation of the baseline demand system.

In the counterfactual analysis of changes to electricity prices, in Chapter 5, sensitivity analysis is limited to high level model specification choices, purely because of the computationally intensive nature of the analysis and the time taken to run counterfactual analyses. However, the intention is that the more extensive sensitivity tests presented in Chapter 4 at least provide a measure of the sensitivity of model results to model specification decisions.

One observes that debates in economics about demand analysis and welfare analysis typically have a highly theoretical basis. For example, with regard to the efficiency of estimators and aggregation problems and the extent to which income effects can be ignored. These are important, however they often provide little guidance as to the practical implications of choosing theoretically ideal estimators over practically feasible estimators or of including or excluding particularly explanatory variables.[15]

[15] The distinction between theoretically ideal models and practically feasible models has the same conceptual character as distinguishing between in principle statistical and economic significance (Mc-

One aspect the methodology which is not tested but perhaps should be in future research, is the decision taken to model responses to average electricity prices faced by households. Models that approximate two-part or multi-part tariffs as a single average price introduce simultaneity bias, by measuring average expenditure per unit instead of the actual menu of prices that consumers are facing (Reiss and White, 2005). In the context of high fixed charges, if consumers make decisions based on marginal prices then responses to a two-part tariff should be modelled sequentially with the fixed access charge in one step and marginal consumption decisions in a subsequent step (Gomez-Lobo, 1996). However if consumers respond to average prices, then it is reasonable to model demand accordingly.[16]

Imperfections in consumer behaviour pose more general problems for model specification, particularly in the context of demand theoretic models based on consumer utility maximisation, as the almost ideal demand systems are. For example, it is possible that some consumers exhibit rational inattention while others make mistakes and still others act according to optimal responses to marginal prices. And these heterogeneous models of consumer decision making may also be perturbed by policy settings.

Thus, there is a case to be made that experimental or quasi-experimental analysis should be preferred for analysing policy and welfare effects, rather than observational studies as used here. The difficulty of course is that experimental analyses require resources that are not always readily available, principally data and time, as was the case here.

Welfare effects and distributional impacts of higher fixed charges are discussed in Chapter 5. The basis for the evaluation follows directly from the demand system analysis, using compensating variation to measure money metric changes in utility. Changes in inequality are also assessed using the Atkinson index. Section 5.1 discusses these metrics in more detail and explains the intuition behind the use of the Atkinson index.

The methods used here, while ostensibly complex, only address a subset of the issues surrounding efficient electricity pricing. The final chapter, Chapter 6, summarises the results of the empirical analysis, provides some commentary on the implications of the

Closkey and Ziliak, 2008) but in the context of model selection.

[16]This issue is not unique to this research. Most demand system estimation relies on the representation of a single price for each product in the demand system.

results for policy and pricing practice, and reflects upon limitations of the analysis and related research that could be undertaken to address those limitations.

Chapter 2

Almost ideal demand systems

This chapter describes the Almost Ideal Demand system (AIDS) and Quadratic Almost Ideal Demand system (QUAIDS) used to analyse impacts of prices on consumer demand and welfare. The first section provides brief context behind the selection of the almost ideal demand systems, over other demand systems. The second section sets out the formal components of the model and the third section discusses estimation methods.

2.1 Model selection

Two versions of almost ideal demand systems are used here to study household expenditure and energy demand: the almost ideal demand system (AIDS)(Deaton and Muellbauer, 1980) and the quadratic almost ideal demand system (QUAIDS)(Banks *et al.*, 1997).

The primary focus is on the QUAIDS model. Up until recently (Thomas, 2019) the QUAIDS model had not been used in published research in New Zealand, although the model has been widely used in demand analysis in other countries. A second reason for the focus on the QUAIDS model is the novel implementation of the model in the open-source statistical software R as discussed later in section 2.3.

The AIDS model is used as a comparator for the results from the QUAIDS model. Typically, demand systems are estimated without any sensitivity tests as to model specification. Rather than testing model specifications, model choice is motivated by discussion of in-principle or theoretical justification or practical tractability. This means it is very difficult, if not impossible, to investigate the effect that model specification has on results of applied analysis. Although research does exist that compares models (Fisher, Fleissig, and Serletis, 2001).

A linear expenditure system has also been used, for comparison purposes, though the basis of this model is not discussed in any detail. The linear expenditure system (LES) has been widely used in New Zealand (Creedy, 2004; Creedy and Sleeman, 2005b, 2006; Ball and Ryan, 2014; Ball *et al.*, 2016), ostensibly due to the influence of John Creedy who has used the LES extensively for welfare analysis of tax changes, has a well-regarded body of work in public economics, and has spent a substantial amount of time researching on and in New Zealand.[1]

Of all the demand systems the LES is simplest to estimate and has the convenient property that estimation can proceed from data on expenditure shares, without the need for data on prices which are comparatively difficult to come by. Welfare analysis can also be conducted using the LES and assumptions about constant marginal utility of income.(Creedy, 1998) Not having to rely on price data is a significant strength of the LES model because it avoids errors in estimation from price heterogeneity and errors in measurement of prices. This comes at the cost of using an inflexible demand system with restrictive assumptions on the form of expenditure functions (Deaton, 1974; Pollak and Wales, 1992) such as constant price-independent marginal budget shares where demand for a product scales linearly with total expenditure.

Estimation of linear expenditure systems, in New Zealand, has typically been undertaken using ordinary least squares estimation of budget shares on a product-by-product basis (Creedy, 2004). The econometric validity of this sort of approach and, for example, the comparatively greater efficiency of system estimation, is not discussed in any detail in New Zealand research. Furthermore, researchers using LES models, in New Zealand, typically do not report the estimated parameters of their models or summary statistics such as elasticities. As a result it is not possible to compare differences across these and other demand models.

The AIDS model, introduced by Deaton and Muellbauer (1980), is less-restrictive

[1] See, for example, Professor Creedy's NZIER Economics Award citation at https://nzier.org.nz/about/economists-award/previous-economics-award-winners/.

than predecessor models of demand including the LES model. It permits, for example, non-linear relationships between demand and total expenditure and consistency with theoretical models of consumer demand based on rational utility maximisation. The less restrictive form of the model, compared to its predecessors, also better enables more reliable testing of demand data for consistency with theoretical predictions of consumer demand: homogeneous of degree zero in income and prices; symmetric changes in demand with respect to relative price changes between two goods; strictly negative compensated own-price elasticities of demand for all goods (a negative semi-definite matrix of substitution elasticities).

Banks *et al.* (1997) proposed the QUAIDS as a response to the observation that existing applied models of consumer demand were restrictive in not accommodating empirically observed non-linear relationships between expenditure shares and total expenditure (non-linear Engel curves). The QUAIDS model overcomes this by adding a quadratic income term to the AIDS model. Much of the following presentation of the theory behind the demand models draws directly from Banks *et al.* (1997).

2.2 Models

The QUAIDS model, for estimation in share form, is:

$$w_i = \alpha_i + \sum_{s=1}^{S} \delta_{is} z_s + \sum_{j=1}^{N} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{m}{a(p)} \right] + \frac{\lambda_i}{b(p)} \left\{ \ln \left[\frac{m}{a(p)} \right] \right\}^2 \tag{2.1}$$

where w_i is the share of expenditure on a product, z_s is a vector of demographic variables, p_j is a vector of prices for all products (including $i = j$), and m is total expenditure.

The terms $a(p)$ and $b(p)$ are, respectively, translog and Cobb-Douglas price indices:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^{N} \left(\alpha_i + \sum_{s=1}^{S} \delta_{js} z_s \right) \ln p_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \gamma_{ij} \ln p_i \ln p_j \tag{2.2}$$

$$b(p) = \prod_{i=1}^{N} p_i^{\beta_i} \tag{2.3}$$

Product specific parameters to be estimated are α_i, β_i, and λ_i. The latter two terms determine expenditure elasticities. The γ_{ij} parameters determine substitution between pairs of products. The δ_{is} parameters shift product demands in response to demographic characteristics.

Adding-up constraints, in the context of share equations in which all shares need to add to one, imply that $\sum_i \beta_i = 0$, $\sum_i \alpha_i = 1$, $\sum_i \delta_{is} = 0\ \forall s$, and $\sum_i \gamma_i j = 0\ \forall j$. Ensuring that expenditure is homogeneous of degree zero in prices and income requires $\sum_j \gamma_{ij} = 0\ \forall i$.

The $\sum_{s=1}^{S} \delta_{is} z_s$ term in equation 2.1 reflects a choice about how to incorporate demographic effects into the QUAIDS model (see section 2.2.1) and differs from the original presentation of the model in Banks *et al.* (1997).

The term on the right-hand side of equation 2.1 distinguishes the QUAIDS model from the AIDS model. That is, the AIDS model to be estimated is:

$$w_i = \alpha_i + \sum_{s=1}^{S} \delta_{is} z_s + \sum_{j=1}^{N} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{m}{a(p)} \right] \tag{2.4}$$

The QUAIDS model follows from an indirect utility function of the form:

$$\ln V = \left\{ \left[\frac{\ln m - \ln a(p)}{b(p)} \right]^{-1} + \lambda(p) \right\}^{-1} \tag{2.5}$$

The model of demand shares in equation 2.1 is obtained from equation 2.5 by defining $\lambda(p) = \sum_{i=1}^{N} \lambda_i \ln p_i$, and using Roy's identity in share form $w_i = -\frac{\partial V}{\partial \ln p_i} / \frac{\partial V}{\partial \ln m}$. The AIDS version of the model derives from a version of the QUAIDS indirect utility function with $\lambda(p) = 0$.

The log expenditure function in the QUAIDS model, which is important for empirical welfare analysis, follows directly from rearrangement of the indirect utility function (with $\ln V = \ln u$):

$$\ln e\,(p, u) = \ln m = \ln a(p) + b(p) \left[\frac{1}{\ln u} - \lambda(p) \right]^{-1} \tag{2.6}$$

2.2.1 Demographic scaling methods

To account for heterogeneity in households, the model needs to accommodate measures of household or demographic differences. This is not straightforward in the sense that there are a limited number of ways that demographic terms can enter demand systems without undermining the relationship between the demand system, as estimated, and underlying indirect utility functions and thus undermining the theoretical validity of welfare analysis.

The general approach to introducing demographics is to posit a reference household around which expenditure varies and in thus demographic differences can expenditure can be expressed as deviations from the reference household - also referred to as equivalence scales. The key choices to be made are whether these scales should be permitted to vary according to total expenditure levels or prices (Blow, 2003).

Here the choice has been made to introduce demographics into equation 2.1 by way of shifts in expenditure or costs that are independent of total expenditure or prices. This is an approach known as demographic translation (Pollak and Wales, 1992) and it is the simplest form if demographic scaling.

An appealing alternative is the price scaling method of Ray (1983) where equivalence scales vary with relative prices and equivalence scales are estimated simultaneously with demand systems. This method addresses identification problems that arise in trying to separate demographic differences in preferences from observed demographic differences in living costs (Ray, 2018, pp. 12-18).

An example of this method, in the context of QUAIDS models, is given in Nicholas, Ray, and Valenzuela (2010) which defines an equivalence scale m_{oh} (the ratio of a household's costs relative to a reference households costs, to meet a given level of utility) as:

$$m_{oh}\left(z,p,u\right) = \prod_k p_k^{\delta_k z_h} \left(a_h + \sum_g \rho_g z_{gh}\right)^{\theta} \tag{2.7}$$

where a is the number of adults in a household, $z_g h$ is the number of children in the household (h) by age group (g), ρ_g is an age-specific equivalence coefficient for children, θ is a scale parameter, z_h is the number of children in the household and the parameter δ captures the sensitivity of the equivalence scale to changes in prices and $\sum_k \delta_k = 0$. This is similar to the equivalence scales estimated in section 4.1.2.

The price-scaled QUAIDS has the same general from as equation 2.1 but $\lambda(p)$ is redefined as $\lambda(p) = \prod_i p_i^{\lambda_i}$ and the price aggregator $a(p)$ includes the additional household composition and scale terms. The model is (Nicholas *et al.*, 2010):

$$w_{ih} = \alpha_i + \delta_i z_h + \sum_{j=1}^{N} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{m}{a(p)} \right] + \frac{\lambda(p)}{b(p)} \left\{ \ln \left[\frac{m}{a(p)} \right] \right\}^2 \tag{2.8}$$

$$\begin{aligned} \ln a(p) =& \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \gamma_{ij} \ln p_i \ln p_j + \\ & \theta \left(a_h + \sum_g \rho_h z_{gh} \right) + \sum_i \delta_i z_h \ln p_i \end{aligned} \tag{2.9}$$

$$\lambda(p) = \prod_i p_i^{\lambda_i} \tag{2.10}$$

$$b(p) = \prod_{i=1}^{N} p_i^{\beta_i} \tag{2.11}$$

The addition of price dependence substantially increases the number of non-linear terms in the model and significantly complicates estimation procedures. In particular, the household scale and child weight parameters, θ and ρ, inside $a(p)$ do not have counterparts elsewhere in the model, unlike the model with demographic translation where all demographic terms can be found inside and outside $a(p)$. This means that model cannot be solved via iterated linear methods (see section 2.3). Nicholas *et al.* (2010) estimate the model using commercial software with well-tested non-linear system estimation.[2] Building a reliable nonlinear system estimation algorithm proved too complex for this study.[3]

2.2.2 Demand elasticities

The following documents the standard formulas for the expenditure and price elasticities of demand for the AIDS and QUAIDS models. The elasticities for the AIDS model

[2]SAS and Stata non-linear Full Information Maximum Likelihood.

[3]There are no pre-established or reliable nonlinear system estimation procedures in R. Constructing an estimation algorithm from scratch was investigated but considered unwise because of the amount of time that would be required to test the algorithm and ensure its reliability. With a large non-linear system estimation would likely be slow and success (convergence) not guaranteed. In principle, it would have been possible to shift between software platforms in order to reliably estimate the price-scaled QUAIDS. This was, however, inconsistent with the approach taken here to adapt open-source software in order to fully understand the estimation procedures and assumptions in the analysis (see section 2.3).

follow the formulas presented in Green and Alston (1990) and the elasticities for the QUAIDS model follow directly from those in Banks *et al.* (1997).

These elasticities depict proportional changes in demand based on the partial derivatives of the expenditure systems, with respect to income and prices, and provide a useful summary statistic of the properties of the demand system when they are evaluated for a given set of initial prices and expenditure (typically mean values).

The elasticity formulae are provided here, and referred to in model results to follow, to provide intuitively understandable summary statistics. Elasticities are commonly used both summary statistics and as parameters for evaluating welfare effects. However they are not primitives of the model. The use of elasticities to describe economic relationships and to infer welfare effects can thus be misleading, such as when they are used to consider the effects of large price changes rather than small ones (Chetty, 2009).

Expenditure elasticities

The expenditure elasticities for each good (η_i) of the AIDS and QUAIDS models, denoted with superscripts a and q in equations 2.12 and 2.13 respectively, are:

$$\eta_i^a = 1 + \frac{\beta_i}{w_i} \tag{2.12}$$

$$\eta_i^q = 1 + \frac{\beta_i}{w_i} + \frac{2\lambda_i}{w_i b(p)} \left\{ \ln \left[\frac{m}{a(p)} \right] \right\} \tag{2.13}$$

Uncompensated price elasticities

The uncompensated or Marshallian price elasticities of demand for each good (e_{ij}) of the AIDS and QUAIDS models, in equations 2.14 and 2.15 respectively, are:

$$e_{ij}^a = \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i} \left(\alpha_i + \sum_{s=1}^{S} \delta_{is}^z z_s + \sum_{k=1}^{N} \gamma_{kj} \ln p_k \right) - \delta_{ij}^k \tag{2.14}$$

$$
\begin{aligned}
e^q_{ij} =& \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i}\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \\
& \frac{2\lambda_i}{w_i b(p)}\left\{\ln\left[\frac{m}{a(p)}\right]\right\}\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \\
& \frac{\lambda_i\beta_j}{w_i b(p)}\left\{\ln\left[\frac{m}{a(p)}\right]\right\}^2\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \delta^k_{ij}
\end{aligned}
\tag{2.15}
$$

where $\delta^k_{ij} = 1$ when $i = j$ and is otherwise equal to 0.

These uncompensated price elasticities of demand reflect changes in demand for a product, inclusive of income effects, when either the price of that product changes ($i = j$ or own-price elasticity) or the price of another product changes ($i \neq j$, or cross-price elasticity). These price elasticities reflect what one would expect to observe, in terms of expenditure changes, when prices change.

Compensated price elasticities

The compensated or hicksian[4] price elasticities of demand reflect welfare-theoretic changes in demand, in response to prices. The term *compensated* is used to reflect that the hicksian elasticities capture how demand would change if people were compensated for any income effects from price changes.

The hicksian price elasticities of demand for each good (h_{ij}) are the sum of the uncompensated demand elasticities and the expenditure elasticities weighted by the expenditure share of the product that is changing in price.[5] The relevant formulae are presented in equations 2.16 and 2.17 for the AIDS and QUAIDS models respectively:

$$
h^a_{ij} = \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i}\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \delta^k_{ij} + w_j\left(1 + \frac{\beta_i}{w_i}\right) \tag{2.16}
$$

[4]So-named for John Hicks' (1904-1989) whose work distinguishing substitution and income effects was pioneering in the English-speaking world (Bliss, 2017)

[5]Derived from the Slutsky equation relating demand changes to component income and substitution effects.

$$
\begin{aligned}
h_{ij}^{q} =& \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i}\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \\
& \frac{2\lambda_i}{w_i b(p)}\left\{\ln\left[\frac{m}{a(p)}\right]\right\}\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \\
& \frac{\lambda_i\beta_j}{w_i b(p)}\left\{\ln\left[\frac{m}{a(p)}\right]\right\}^2\left(\alpha_i + \sum_{s=1}^{S}\delta_{is}z_s + \sum_{k=1}^{N}\gamma_{kj}\ln p_k\right) - \delta_{ij}^{k} + \\
& w_j\left(1 + \frac{\beta_i}{w_i} + \frac{2\lambda_i}{w_i b(p)}\left\{\ln\left[\frac{m}{a(p)}\right]\right\}\right)
\end{aligned} \tag{2.17}
$$

2.3 Estimation methods

Model estimation methods have been adapted from those in the R package *MicEconAids* (Henningsen, 2017). The package provides a useful starting point as it contains a range of standard methods for estimating AIDS models.

Adaptation of open-source software provides for a greater understanding of assumptions and methods used during estimation and, in principle, provides a basis for future extensions or adaptations not easily added to commercial software.

There are other more complete commercial software programmes available for estimating QUAIDS and AIDS models (Poi, 2012). However, estimation procedures in commercial software are typically less transparent, less readily tested and less well-understood than estimation methods based on open-source software where the underlying code can be interrogated in great detail.

Numerous adaptations and extensions were made to the *MicEconAids* component programmes in order to estimate the AIDS and QUAIDS models as set out in section 2.2. This was necessary because the *MicEconAids* package does not provide for estimation of QUAIDS models or calculation of elasticities for AIDS models that include demographic variables.

Extending the *MicEconAids* package to be able to estimate QUAIDS models included: addition of quadratic income terms and associated λ coefficients; addition of a Cobb-Douglas price index $b(p)$; extending system estimation set-up programmes to include restrictions on the λ values; introducing a procedure for calculating standard errors of elasticity estimates, based on the delta method; extending calculations of Jacobian matrices for estimating coefficient variance-covariance matrices (Henningsen, 2017, p. 10).[6] Extensive changes were made to the package's programmes to ensure that additional coefficients would be accepted as function arguments in the various component programmes.

In *MicEconAids* and the extended version for QUAIDS, the delta method is used to estimate covariance matrices, and standard errors, for elasticity values (Henningsen, 2017, p. 17). This method provides an approximation of the variance of a transformed random variable (in this case the elasticities) using the matrix of partial derivatives (the Jacobian) of the transformed variable with respect to the model coefficients and the covariance of the model coefficients.

Bootstrapping was considered as an alternative to the delta method and for comparison with the delta method. However, bootstrapping proved to be impractical, for the QUAIDS model, because the iterative estimation methodology frequently failed to converge when the model was estimated on sub-samples and because of the considerable amount of time required to repeatedly estimate the model.

Extending the delta method to the QUAIDS model elasticities was non-trivial, due to the number of additional terms in the QUAIDS model as compared to the AIDS model and consequently more complicated partial derivatives of the elasticity functions with respect to the model parameters. The calculated partial derivatives are presented in appendix B, excluding the partial derivatives of the elasticity calculations with respect to demographic variables as these are trivial.

The extensions of the AIDS model programmes focused solely on calculation of elasticities, with adaptations made to include demographic variables in elasticity calculations and also to extend the delta method for calculating elasticity standard errors by adding partial derivatives for demographic variables.[7]

The estimation procedure used here and in the *MicEconAids* package is iterated seemingly unrelated regressions. While AIDS models can be successfully estimated

[6]This latter extension involved calculating partial elasticities of share equations for the additional parameter and extending the size of the Jacobian matrices accordingly.

[7]In addition, an omission was found in the function *aidsCalc* that calculates AIDS model fitted shares and quantities. The function did not take account of demographic variables in calculating fitted shares. This was corrected in the version of the programmes used here.

using linearised versions of the model, using approximations to the translog price index $a(p)$, the QUAIDS model cannot be estimated with a linearised version.

Iterated seemingly unrelated regressions proceeds by positing starting values for the non-linear components of the models, $a(p)$ and $b(p)$ in the case of the QUAIDS model, estimating the models system of demand equations using seemingly unrelated regression, using the estimated model parameters to estimate values for $a(p)$ and $b(p)$, and then repeating the estimation procedure until the parameter values converge. Parameters are deemed to have converged to stable values once changes in parameter values, between adjacent iterations, are smaller than exogenously determined level of tolerance.[8]

Alternative approaches make use of non-linear system estimation procedures that use gradient search to estimate coefficient values. Gradient search is similar to iterated regressions in the sense that it is iterative, however it is slower and less likely to converge because each step requires non-linear rather than linear calculations. Furthermore, while non-linear estimation has the potential to be more robust, it also requires well-developed and extensively tested search algorithms, which are not readily available or adaptable in the case of the open-source software R.

[8]The measure of change is the square root of the ratio of the sum of squared coefficient changes to the sum of squared coefficient values in the updated model.

Chapter 3

Household expenditure and price data

This chapter describes the expenditure and price data used to estimate the QUAIDS and AIDS models. A novel data set has been constructed where household expenditure data is extended with data on average electricity prices by electricity distribution network area.

This data is not without its limitations, as discussed below, but it complements alternative data and analyses that are either based on detailed commercial data on electricity expenditure and prices combined with high level socio-demographic aggregates or based on detailed household expenditure and socio-demographic data combined with high level average price indices.

3.1 Household Economic Survey

The principle source of data is unit record survey data from the Household Economic Survey (HES) expenditure survey conducted every three years by Stats NZ Tatauranga Aotearoa (Stats NZ).[1] The data includes surveys for the five years ended in June 2007,

[1] Access to confidentialised data was granted by Stats NZ under conditions of confidentiality including limitations on the form of data that can be released. This limits the amount of descriptive detail that can be presented here.

2010, 2013, 2016, and 2019. Each survey has a sample size of approximately 5,500 and is designed to achieve a response rate of approximately 3,000.[2]

The sample sizes used for this analysis are summarised in Table 3.2. Data-cleaning has been undertaken to remove outliers with implausible survey responses. For example, households with expenditure on electricity exceeding 40 percent of total household expenditure were removed from the data, resulting in a small proportion of observations being removed. Survey responses that had missing location information were also removed because of the need for information on territorial local authority of residence to assign prices to a household (refer section 3.2). Inferences to the wider population of households are based on population weights constructed by Stats NZ, adjusted for reduced sample sizes through data-cleaning.

3.1.1 Household categories

Household types, used to help summarise data and results, are categorised according to number of adults and number of children in the household. Single (one adult) and couple (two adult) households are further categorised into households were the age of the reference person in the household is 65 or older, denoted 65+, or under 65.[3] This follows the household categories used in Creedy (2004) and acknowledges that income and expenditure patterns change in retirement (Aguiar and Hurst, 2013).

3.1.2 Product categories

Table 3.1 provides a summary of the product categories used including sample mean and population-weighted mean expenditure shares over all household expenditure surveys. Definitions of product groups are created to give the most geographical variation in product prices possible, given publicly available price indices, to maximise observed

[2]Details of the surveys are available on Stats NZ's metadata repository DataInfo+, for example details of the June year 2019 was available at http://datainfoplus.stats.govt.nz/Item/nz.govt.stats/c89bb0e9-0cfb-48e6-b338-59ed7c7ee31b (accessed 7 June 2020).

[3]The reference person, the primary representative of the household, is the person having primary responsibility for tenancy or ownership of the dwelling and is typically acknowledged as such by the other members of the household.

price variation and reduce the amount of averaging across products.

Table 3.1: Mean expenditure shares by product group

Product group	Sample mean	Population mean
Accommodation	22.4%	22.2%
Air transport	1.8%	1.7%
Alcohol	2.8%	2.8%
Clothing	2.6%	2.6%
Communications	3.9%	3.9%
Contents	4.2%	4.2%
Education	1.1%	1.1%
Electricity	5.0%	4.9%
Groceries	14.7%	14.8%
Health	2.7%	2.6%
Insurance	5.2%	5.1%
Mortgage interest	5.3%	5.5%
Other energy	0.6%	0.6%
Miscellaneous	7.0%	6.9%
Recreation	9.2%	9.1%
Eating out	4.1%	4.2%
Transport	7.5%	7.8%

Mean over HES surveys 2007, 2010, 2013, 2016, 2019.

The categories are: accommodation, including rental costs; air transport; alcohol and tobacco; clothing and footwear; communications, including telecommunications equipment and services; household contents, including appliances; takeaways and eating out, includes ready-to-eat meals; education; electricity; food, encompassing groceries and excluding ready-to-eat food; health spending, such as dental services and pharmaceutical products; insurance, including contents and life; other or miscellaneous spending such as jewellery and personal and professional services; mortgage interest; other energy, gas and solid fuels; recreation and cultural services, including recreation equipment; transport, including transport fuels and public transport.

In the analysis we include accommodation costs. This has been excluded in other analyses, due to the problem that consumption of owner occupied accommodation is not observable (Thomas, 2019). However ignoring accommodation altogether, due to unobserved imputed rental values, is not without its problems because changes in accommodation costs can have a non-trivial effect on total expenditure over time. The consumption choices of considerable numbers of households are affected by changes in, for example, mortgage interest rates and accommodation costs over time. The intent is to analyse changes in consumption decisions over time (see discussion in section 4.1) so it was considered better to include measures of accommodation-related spending in the analysis, despite measurement problems.

Two separate measures of housing-related costs are included. One is housing costs based on rental payments and rates (labelled accommodation). The other is mortgage interest payments, comprising that part of mortgage payments that represents a credit service rather than savings.

A full list of the composition of products within each product group is in Table A.1 in Appendix A.

Table 3.2: Counts of households in sample

	Year of survey:				
Household	2007	2010	2013	2016	2019
Single - no children	333	324	345	354	414
65+ single	258	264	345	369	375
Single - 1 child	96	99	90	63	90
Single - 2 children	45	45	60	48	72
Single - 3+ children	24	33	27	27	39
Couple - no children	615	681	627	654	741
65+ couple	252	315	336	384	375
Couple - 1 child	237	261	228	252	258
Couple - 2 children	279	297	252	267	303
Couple - 3+ children	138	141	120	141	150
3 adults - no children	132	183	147	174	192
3+ adults - 1+ children	156	150	141	150	204
4+ adults - no children	72	90	57	84	102
Total	2,637	2,883	2,775	2,967	3,315

3.1.3 Electricity expenditure

HES data on electricity expenditure has been seasonally adjusted to correct for bias based on when households were surveyed (see appendix Table C.1 for estimated seasonal adjustment factors).

HES estimates of electricity expenditure are based on the most recent bill received by a household when surveyed and, as a result, estimates of annual expenditure vary considerably by survey month. For example, Figure 3.1 shows estimated annual expenditure on electricity is consistently higher for households surveyed in the coldest months of the year; New Zealand being a country where demand peaks in the winter, for heating.

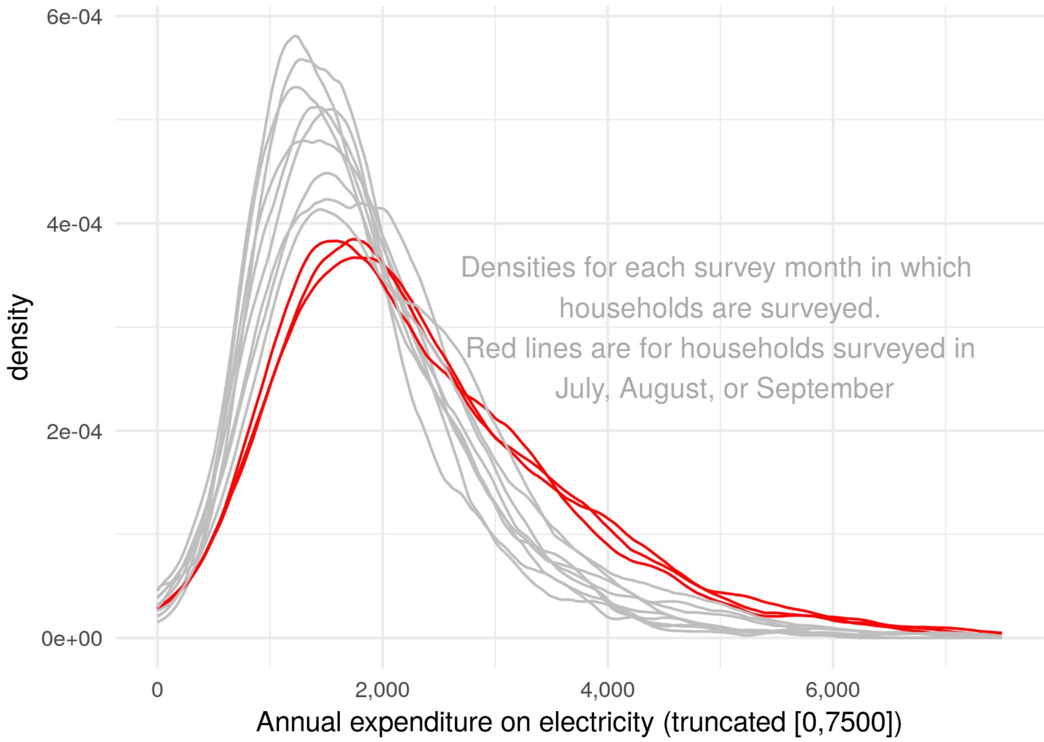

Figure 3.1: Annualised electricity expenditure by survey month for HES surveys 2007, 2010, 2013, and 2016.

Electricity expenditure exhibits economies of scale and expenditure shares that decline as income increases. Economies of scale can be seen in Table 3.3 where expenditure shares tend to be smaller for larger households.

Expenditure shares consistently decline as income increases, with the only exception being the increase in expenditure shares from the first to the second quintile of income for single-parent households with three or more children - an exception likely influenced by variance in household sizes within this household type.

Table 3.3: Electricity expenditure, share of total expenditure

	Real disposable income quintiles:				
Household type	1	2	3	4	5
Single - no children	0.089	0.064	0.051	0.039	0.032
65+ single	0.093	0.088	0.084	0.065	0.056
Single - 1 child	0.071	0.066	0.055	0.053	0.034
Single - 2 children	0.079	0.069	0.058	0.054	0.033
Single - 3+ children	0.060	0.082	0.065	0.046	0.041
Couple - no children	0.063	0.046	0.039	0.034	0.028
65+ couple	0.073	0.072	0.056	0.050	0.043
Couple - 1 child	0.060	0.046	0.042	0.033	0.030
Couple - 2 children	0.056	0.041	0.040	0.032	0.026
Couple - 3+ children	0.061	0.056	0.042	0.037	0.033
3 adults - no children	0.057	0.047	0.038	0.034	0.028
3+ adults - 1+ children	0.066	0.048	0.048	0.038	0.029
4+ adults - no children	0.054	0.035	0.033	0.030	0.025

Values: Population weighted mean expenditure shares.

Quintiles: Lowest (1) to highest (5) household incomes.

Income quintiles are conditional on survey year and household type.

Sample: HES surveys 2007, 2010, 2013, 2016, 2019.

Notably the sampled HES survey data includes May and June months in 2019 when expenditure may have been influenced by the introduction of a winter energy payment. In 2019 the New Zealand government introduced a winter energy payment for recipients of benefits, including NZ Superannuation, of \$20.46 a week for single people and \$31.82 couples or people with dependent children. Payments were made for 22 weeks from 1 May and were not tied to energy expenditure. As a share of spending on electricity, winter energy payments amount to 40 percent of annual expenditure for sole-occupant and couple households in the lowest quintile of disposable incomes.

Although the winter energy payment was not tied to spending on energy, it is possible the payment increased spending on energy, including electricity, by more than would otherwise be expected due to the fact that the payment was labelled as being for energy costs. As discussed in section 1.2, an evaluation of a similar scheme in the United Kingdom (Beatty *et al.*, 2014) found that almost half of the money paid was spent on energy and more than ten times the amount predicted from observed expenditure elasticities.

Estimated kilowatt-hour consumption

Electricity consumption, in kilowatt-hours (kWh), has been estimated by deflating expenditure by estimated average prices (refer section 3.2) as the HES does not include measures of consumption volumes. These estimates, summarised in Table 3.4, are imprecise because they assume a common set of average prices by local council area (territorial local authority) but they are consistent with ranges of electricity consumption volumes published in analysis of market data on residential electricity consumption as part of the government's 2018 Electricity Price Review (New Zealand Government, 2018). These estimates complement those based on market data because they are combined with detailed information on household characteristics while analysis based on market data can only infer household characteristics, such as household size and income, from geographic aggregates.

Table 3.4 shows patterns of consumption that vary less consistently with household size and income than do expenditure shares. This reflects the fact that the consumption estimates shown in the table are affected by variation in prices, variation in incomes over time[4] and variation in expenditure. The data show that electricity consumption increases with both household size and with income but that household size has a larger effect on electricity consumption than does household income. That is, variation in electricity consumption within household types is smaller than variation across across household types. Nonetheless the consumption estimates also support the observation that there are non-trivial economies of scale in electricity consumption. For example, the addition of second household member in the lowest income quintile is associated with a 32 percent increase in electricity consumption, on average. The addition of a third household member is associated with a 21 percent increase in electricity consumption, on average.

[4]The disposable income quintiles are conditional on survey year.

Table 3.4: Estimated mean kWh electricity consumption

	Real disposable income quintiles:				
Household	1	2	3	4	5
Single - no children	5,032	5,275	5,701	5,499	5,462
65+ single	5,727	5,079	5,471	5,227	6,076
Single - 1 child	6,347	6,618	7,280	7,103	7,408
Single - 2 children	8,219	7,599	7,492	8,779	8,693
Single - 3+ children	8,547	9,539	8,085	8,503	8,584
Couple - no children	7,197	7,673	7,948	8,195	9,747
65+ couple	7,542	7,245	7,561	8,276	9,563
Couple - 1 child	8,679	8,813	8,692	9,003	11,464
Couple - 2 children	10,100	9,165	10,232	10,675	11,442
Couple - 3+ children	9,725	10,682	10,588	11,596	13,596
3 adults - no children	8,987	9,324	9,960	9,605	11,029
3+ adults - 1+ children	10,269	11,311	12,357	11,608	12,499
4+ adults - no children	10,185	9,853	11,304	11,314	11,369

Values: Population weighted mean kWh.

Quintiles: Lowest (1) to highest (5) household incomes.

Income quintiles are conditional on survey year and household type.

Sample: HES surveys 2007, 2010, 2013, 2016, 2019.

3.2 Prices

Data on prices are from the Statistics New Zealand Consumers Price Index (CPI) series and the Quarterly Survey of Domestic Electricity Prices (QSDEP) produced by the New Zealand Ministry of Business Innovation and Employment (MBIE).

3.2.1 Consumers price indices

Price indices by product group have been constructed using two steps that produce price indices that best approximate both product group prices and spatial variation in prices.

In the first step national CPI data by class is aggregated to product groups using expenditure weights from Stats NZ (2018) and a June quarter 2017 base period. CPI class is the third level of the consumer price index with detailed product categories such as fruit, vegetables, beer and men's footwear (see components of product groups in Table A.1 in appendix A).

In the second step, price indices are adjusted for geographic variation where data is publicly available. This involves estimating regional rates of inflation relative to national rates of inflation and adjusting national indices up or down in accordance with these relative differences. In the final analysis these adjustments are not large except in the case of accommodation costs.[5]

CPI data has limited spatial variation due to the limited sample size in the HES, which is used to construct expenditure weights, and limited coverage of surveyed prices. This means that regional CPI indices, where available, are typically at high-level geographic groupings.

To infer spatial variations in prices we match households to regional CPI measures based on the territorial local authority (TLA) in which the household resides and the region in which the territorial authority is located. The main regional groupings in the CPI are: Auckland, Wellington, rest of north island, Christchurch, rest of south island. In addition, the food price index (FPI) includes prices by main centre of price surveys: Whangarei, Auckland, Hamilton, Tauranga, Rotorua, Napier-Hastings, New Plymouth, Whanganui, Palmerston North, Wellington, Nelson, Christchurch, Timaru, Dunedin, Invercargill.[6]

Regional CPI data is typically aggregated at higher levels of product groups than the product groups of interest here. The main regional indices consist of: food, alcoholic beverages and tobacco, clothing and footwear, housing and household utilities, household contents and services, health, transport, recreation and culture, and miscellaneous goods and services. Thus, some of the product groups used in this study have direct analogues in the regional CPI data (such as alcohol and tobacco) while for others regional variation in prices must be inferred indirectly based on movements in

[5]For example, correlations in food price inflation across main centres is 0.90 or larger for all pairs of main-centres.

[6]Indices for Rotorua and Timaru were discontinued in 2014, but have been extrapolated using growth in nearest neighbour price indices.

higher level product aggregations. The concordance between product categories and regional indices is set out in Table 3.5.

Price indices for electricity and for groceries are constructed using more detailed spatial variations in product group prices.

Table 3.5: Product groups matched to regional CPI groups

Product group	Regional CPI match
Acommodation	Housing and household utilities
Air transport	Transport
Alcohol	Alcohol
Clothing	Clothing
Communications	Miscellaneous goods and services
Contents	Household contents and services
Education	None - national CPI used
Electricity	None - QSDEP used
Groceries	FPI by main centre
Health	Health
Insurance	Miscellaneous goods and services
Mortage interest	None - national CPI used
Other energy	None - national CPI used
Miscellaneous	Miscellaneous goods and services
Recreation	Recreation and culture
Eating out	Food
Transport	Transport

This method of inferring regional price differences is sub-optimal but arguably better than assuming a single average national price index. The main area of concern in using regional price indices is that these high-level aggregations will not accurately reflect wide-ranging differences in prices of non-tradable products due to local variation in population density, competition and land prices.

3.2.2 Electricity prices

Electricity price data from the QSDEP measures mean posted electricity prices by electricity distribution network areas based on standardised household consumption profiles and the lowest cost retail tariff available.

The standardised household consumption profiles are based on typical seasonal and daily use and average annual consumption set at an approximate national average of 8,000 kWh per year. The standardised consumption profile also assumes that the household has a service that can be controlled by the distribution network operator (prices for controlled connections are lower than prices for uncontrolled connections) and that the household pays its bills on time.

A concordance is created to align QSDEP network areas with locations by territorial local authority. This correspondence is imprecise in the sense that several network areas span multiple local authorities as shown in Table A.2 in appendix A. However there is a one-to-one correspondence between network areas and major population centres; consequently the impact of this imprecision is immaterial in light of the concentration of expenditure survey coverage in major population areas.

Unobserved variation in prices is a problem for this data, albeit a problem that is true of all price indices. That is, in practice there is considerable variation in: prices posted by retailers, prices paid by consumers, and prices observed by consumers. Only a portion of this variation is captured in geographic differences.

Other sources of variation include consumer inertia, with many households comparing electricity prices only infrequently and remaining on the same tariff for several years, household needs and knowledge[7], and retail competition.

By way of illustration, Figure 3.2 shows the wide range in posted retail tariffs, evaluated at two different levels of consumption and separated according to whether or not tariffs are low fixed rate tariff options. The Figure excludes lines charges, which vary consistently by geographic area. According to the study that this Figure is taken

[7] In recent years electricity retailers have begun to provide prices that pass wholesale energy prices on to consumers and these prices are generally much cheaper than other prices but only where consumers are sufficiently knowledgeable or adept as to be able to control their exposure to wholesale market price spikes

from (Sense Partners, 2018), all network areas experienced widening price dispersion in the period 2013 to 2017 and this was due to increased retail competition.

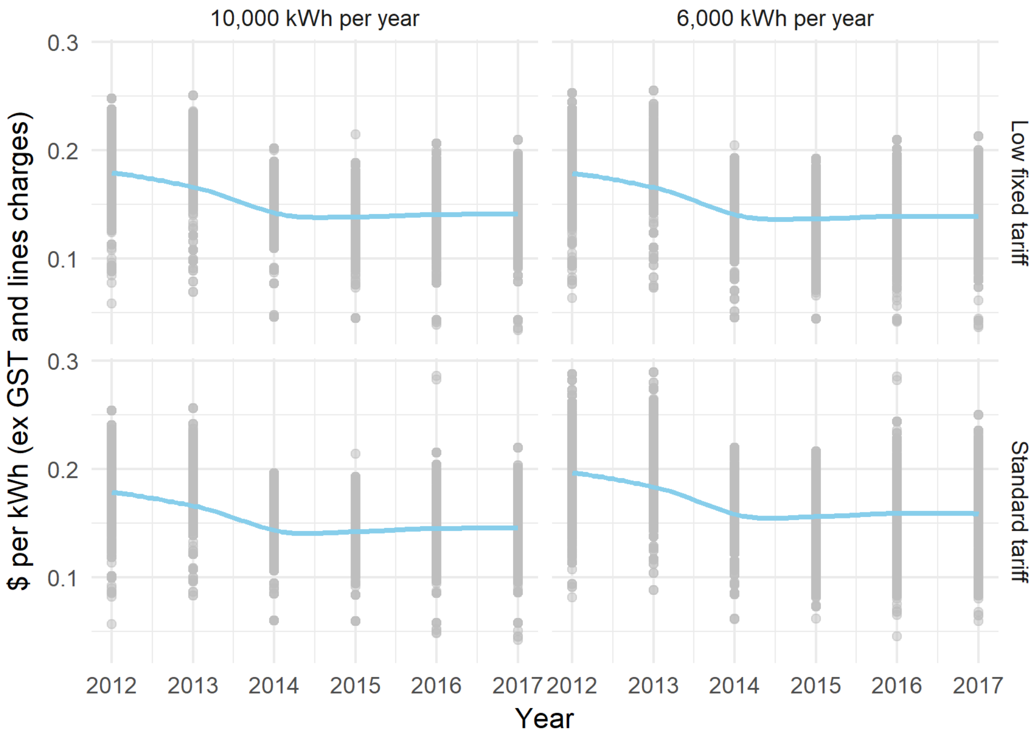

Figure 3.2: Variation in posted retail prices by consumption level and high-level tariff type. Grey dots are average revenue per user for each posted tariff. Blue lines are arithmetic averages. Source: Sense Partners (2018)

In addition, in the past decade, as retail competition has increased, retailers have been offering large discounts to retain customers that are considering switching retailer or to acquire new customers. Some of these discounts are one-off cash payments or fee-free periods while others consist of providing new customers with appliances such as televisions. This sort of discounting behaviour is usually excluded from price indices, which are intended to measure general rather than bespoke prices. However, where a household has received a large discount this could affect consumption and expenditure decisions but the relevant, implicit, price effect will not be observed in the price data and consequently prices will be biased on the high side. That said, this is less of a problem for analysis that analyses broad price trends over several years, as is the case here, than for measuring short term price response.

These issues represent fundamental conceptual and practical difficulties for all price measurement and demand analysis. The simplest example being that the construction of price indices based on expenditure weights which introduces endogeneity into price measurement and creates bias, typical overstating consumer price inflation. Furthermore, in practice, observed prices that are approximated with a single price overlook the effect that menus of prices have on demand. In demand analysis, ignoring menus of prices in favour of a single price causes omitted variable bias (Chernozhukov, Hausman, and Newey, 2019). These issues are not resolved here but they are noted in so far as they represent one of the several trade-offs or simplifications that must be made in almost any analysis of consumer demand.

Chapter 4

Baseline empirical demand system

This chapter describes the baseline demand models that have been estimated. It includes discussion of decisions made about practical empirical and model specification matters such as the range of demographic variables used in the estimation. Estimation results are presented, principally in terms of estimated elasticities of demand. The models produce elasticities that are atypical relative to overseas research, and this is discussed. A final section discusses the sensitivity of the models to alternative specifications and variables.

4.1 Empirical models estimated

4.1.1 Demand systems

Table 4.1 summarises the number and nature of the demand system models that have been estimated. The focus of this chapter is on the first two models. Models (3)-(10) provide for tests of model specification and inference about the sensitivity of the model to model specification.

As will become apparent, the choice of a QUAIDS model over an AIDS model has a material effect on the results of the empirical model. And, in general, the functional form of the model has a larger effect than choice over exogenous demographic variables.

Table 4.1: Models estimated

	Model	HES years	N	Restrictions	Demographic variables
(1)	QUAIDS	2007-2019	14577	Hom, sym	Household size (equivalance scale), reference person age, square of reference person age, log of 1 + share of income from benefits, residual on first stage regression.
(2)	AIDS	2007-2019	14,577	Hom, sym	As in (1).
(3)	QUAIDS	2007-2019	14,577	Hom	As in (1).
(4)	QUAIDS	2007-2019	14,577	None	As in (1).
(5)	AIDS	2007-2019	14,577	Hom, sym	As in (1).
(6)	AIDS	2007-2019	14,577	Hom	As in (1).
(7)	AIDS	2007-2019	14,577	None	As in (1).
(8)	QUAIDS	2007-2019	14,577	Hom, sym	As in (1), number of adults, number of children.
(9)	QUAIDS	2007-2019	14,577	Hom, sym	As in (1), location in upper north island, location in upper south island, location in lower south island.
(10)	QUAIDS	2013, 2016, 2019	9,057	Hom, sym	As in (1).

Restrictions: Homogeneity (Hom), symmetry (sym).

The main demographic variables chosen for the models and common to all models are: household size as measured by an estimated equivalence scale (see section 4.1.2); the age of the reference person in a household, to control for life cycle effects (Banks, Blundell, and Preston, 1991); the square of the age of the reference to capture any non-linearity in life-cycle effects (following the first empirical estimation of a QUAIDS model in Banks *et al.* (1997)); the natural logarithm of one plus the share of household income from benefits, to proxy for the extent of households' connections to the labour force (Aguiar and Hurst, 2013); the residuals from a first stage regression of the natural logarithm of total expenditure on demographic variables and log real disposable income (Banks *et al.*, 1997)). A sample of the first stage regression, for the baseline QUAIDS model, is set out in appendix C.2.

Other examples of QUAIDS models in the literature include a larger number of demographic variables. For example, Thomas (2019) includes: equivalence scale, number of adults, number of children, age of reference person, a dummy variable for gender of reference person, a dummy variable for households in Auckland, a dummy variable for households with a reference person who identifies as New Zealand European (pakeha), a dummy variable for households with a reference person with a tertiary qualification, a dummy variable for households with a reference person whose highest qualification is a secondary qualification, a dummy variable for any household with at least one adult in full time employment, time dummies for each survey quarter.

The approach taken here is to prefer parsimonious specification of demographic variables, keeping the number of variables to those with clear theoretical underpinnings or empirical justification. Setting this approach at the outset also helps to avoid the temptation to engage in data mining where variables are added or removed to achieve intuitively appealing parameter values and thus confirming the bias of the modeller.

In contrast, most other studies[1] add numerous demographic variables with limited or no theoretical justification, no model specification testing, and often without reporting parameter estimates that might be used to test theories around influences on household preferences or tastes (as is the case in Thomas (2019)). For example, Thomas (2019) includes equivalence scales, which are a measure of household scale, and also numbers of children and numbers of adults in household. This seems to apply household scale measures twice and raises questions about collinearity and whether the additional variables make sense. That said, a version of the QUAIDS model (model (8) in Table 4.1) has been estimated with number of adults and number of children in a household as explanatory variables, to test the sensitivity of the model specification to the inclusion of these variables.

It is also common practice to make extensive use of the characteristics of survey reference persons (notional heads of households) to infer demographics without establishing what is being measured with these characteristics, in terms of household composition. For example, it is unclear, empirically, whether or to what extent ed-

[1]Exceptions include Blacklow, Nicholas, and Ray (2010), which relies exclusively on numbers of children and numbers of adults to capture demographic variation, albeit in the context of a price-scaled QUAIDS model.

ucational achievement of the survey reference person is representative of educational achievement in the household overall. While there is evidence of positive sorting of couples by skill or educational attainment (Fernández, Guner, and Knowles, 2005), which would tend to imply that the reference person's educational achievement might be a sound proxy for household characteristics, it is also the case that there are large cohort effects in educational participation and attainment and also gender differences amongst cohorts. Broad categories of educational attainment are also apt to correlate strongly with income, other things being equal. These observations all raise a question about what precisely is being measured with educational attainment as a demographic variable in demand system estimation. Similar questions can be raised about the inclusion of the household reference person's ethnicity.

Geographic effects have been excluded from the main model QUAIDS and AIDS models in this study, largely because of limitations in the geographical coverage of the HES survey data. Geographic variation might be expected to reflect households' tastes or preferences and also product availability (that is, less eating out in rural areas because of less choice). However, HES survey data is sparse in terms of observations for rural areas and the survey size is too small to be able to employ economically and socially meaningful geographies as explanatory variables such as the territorial authority in which a household resides.

The absence of geographic variation in the main QUAIDS model is potentially problematic given our primary interest in electricity demand and geographical relationships between temperature and energy demand for heating. That being so, a variation of the QUAIDS model (model (9) in Table 4.1) has been estimated using high-level regional groupings consistent with regions used for transmission price setting in New Zealand: upper north island (from Huntly north), lower north island, upper south island (Christchurch and north of Christchurch) and lower south island. This model is used to test the sensitivity of our electricity demand elasticities to the inclusion of regional effects. The reason this has not been included in the main model is that these regional aggregations are too coarse to accurately capture climatic differences.

The QUAIDS and AIDS models estimated in this study do not include year or other time fixed effects. Fixed effects are typically used in other studies (Banks *et al.*, 1997; Jansky, 2013; Thomas, 2019), justified as capturing exogenous preference shifts. However, this comes at a cost because the estimated models cannot be used to infer impacts of changes in prices over time. It means that, in the case of electricity demand, cannot infer changes in demand from investment to avoid higher energy costs. Such changes are of interest to us as costly investment in energy saving technology may increase the value of electricity per kWh used but it comes at an unobserved cost.

Inclusion of time-dummies for survey dates, such as monthly or quarterly dummies, does help to control for seasonal effects in the data. However it also means that the models may miss important changes to consumption decisions over time, in response to price changes. This is particularly so for models estimated on data with large aggregates of products such as a single aggregate for food. While it seems intuitively reasonable to expect a household to make fruit and vegetable selections based on seasonal price variation, it is another matter to assume that households are optimising their budget allocations on all food at every visit to the supermarket. Research on mental accounting suggests that households do not operate this way (Hastings and Shapiro, 2013). In the case of electricity demand, costs are only observed by households after consumption decisions have been made, because people are billed for their electricity only after they have used it. If households do make decisions based on average costs instead of marginal prices, then there will be a material lag between price changes and consumption changes. Including dummies for survey month or quarter severely limits the ability of models to detect lagged consumption responses.

The decision not to include fixed time effects in the model means that all estimated elasticities need to be interpreted as long-run or multi-period adjustment elasticities. The exact interpretation of this is imprecise. However, given that the models are estimated on data from surveys occurring every three years, the results are interpreted as changes occurring over three or more years.

There is a risk that the estimated models are biased if there truly have been preference shifts during the study period (fifteen years from 2007 to 2019). In the case of electricity demand it is possible that there have been underlying preference shifts due, for example, to a large amount of spending on subsidies for home insulation and installation of heat pumps between 2009 and 2013. These subsidies, available to all houses built before the year 2000, while essentially reducing costs of energy consumption, are akin to preference shifts from an empirical perspective. Grimes, Preval, Young, Arnold, Denne, Howden-Chapman, and Telfar-Barnard (2016) showed that the insulation subsidy reduced household energy consumption by two percent on average and heat pump subsidies increased electricity consumption and in some cases increased total energy consumption. To test the sensitivity of the model to this programme or other preference shifts we estimate a version of the QUAIDS model on a sub-sample of the data (2013-2019, model (10) in Table 4.1) that post-dates the period in which the government energy efficiency programmes was initially established and most active.

We do not control for censored observations (zero observed expenditure) though some other studies do (Gomez-Lobo, 1996) by Heckman correction.[2] This may introduce some bias into our estimates.

Purchase of vehicles has been excluded from the data as this data was extremely sparse and very volatile. Purchase of other durables have not been removed from the data, though they tend to be in most other demand system estimations. Durables are included in light of the longer-run perspective taken in our models, where durable expenditure and trade-offs between short-run variable costs and longer-run durable costs are an important consideration. Studies that include durables in estimated demand systems typically have an objective of understanding these sorts of dynamics (Blanciforti and Green, 1983; Hummels and Lee, 2017; Rapson, 2014). Our models also do not control for appliance ownership or housing condition as has been done in other energy demand studies using micro-data (Reiss and White, 2005). This is because of unavailability of reliable data.

The demand systems that have been estimated include all seventeen commodity groups listed in Table 3.1. This significantly complicates estimation but has the advantage that substitution possibilities are more accurately specified. Most studies constrain the number of commodity groups to less than ten which has the benefit of simplifying estimation but imposes a cost in terms of excessive averaging of price changes.

A linear expenditure system (LES) has also been estimated, for comparison with the results of the almost ideal demand systems. This is discussed briefly in section 4.3.3.

[2]Estimating first stage choice models (probit models of non-zero expenditure) and using the inverse mills ratio from the regressions as explanatory demographic variables in the demand system

4.1.2 Equivalence scales

Rather than integrate the estimation of household equivalence scales into our model we pre-estimate this using the methods of Creedy and Sleeman (2005a).[3] The model used is:

$$m_i = (a + \gamma c)^{\theta} \tag{4.1}$$

The scales are summarised below in Table 4.2 alongside other equivalence scales commonly used or referred to in New Zealand.

The equivalence scales estimated for this analysis suggests economies of scale larger economies of scale in household operation ($\theta = 0.40$) that are larger (smaller θ) than are usually used in income analysis in New Zealand.

For many years the Jensen scale was used in official analysis of incomes in New Zealand, but recently there was a change to using the modified OECD scale for ease in making international comparisons.[4] The modified OECD scale "assigns the first adult a value of 1.0, the second and subsequent household members aged 14 or older 0.5, and 0.3 for those aged under 14 years"(Ministry of Social Development, 2019, p. 15). Scales estimated by Michelini (2001) using New Zealand household expenditure data have also long been a point of comparison for equivalence scales in New Zealand.

The weight on children in the equivalence scale estimated here is 0.59 and thus larger than the weight on children in the OECD modified scale. The scale parameters are small relative to those estimated elsewhere e.g. in (Michelini, 2001) who estimates an AIDS model with demand shifters. The other equivalence scales do not have explicit scale parameters.

The reason for estimating bespoke equivalence scales for this analysis is that it ensures that the analysis is consistent with the data being used to analyse household consumption demand. The other candidate equivalence scales, based on New Zealand data (Jensen and Michelini) are dated - being based on expenditure data from the 1980s and 1990s. Substantial changes in expenditure have occurred since then, not

[3]We have also examined variations in the expenditure equivalence scales by product. This variation tends to support the use of price scaling, given substantial variation in economies of scale by product.

[4]The Ministry of Social Development (2019) notes that the change in scales makes little difference to analysis.

Table 4.2: Comparison of equivalence scales

		Other scales:		
HH type	Equivalence scale	Jensen	Modified OECD	Michelini
(1,0)	0.72	0.65	0.67	0.57
(1,1)	0.89	0.91	0.87	0.83
(1,2)	1.05	1.14	1.07	1.06
(2,0)	1.00	1.00	1.00	1.00
(2,1)	1.16	1.21	1.20	1.22
(2,2)	1.31	1.41	1.40	1.45
(2,3)	1.47	1.58	1.60	1.65
(3,0)	1.27	1.29	1.33	1.38

HH type is household type defined as (number of adults, number of children). The data for other scales is from the Ministry of Social Development (2019).

Table 4.3: Equivalence scale regression

Dependent: Log of real expenditure

Parameter	Estimate	Std error	T-statistic	P value
Intercept	5.403	0.056	96.02	0
Log real disposable income	0.460	0.005	86.26	0
Log household size (adults + 0.59 x children)	0.405	0.009	42.71	0

Sample: HES expenditure survey 2007, 2010, 2013, 2016, 2019

least because of the effects of economic liberalisation and reductions in price and variety of tradable goods. Furthermore, income growth can cause changes in equivalised household living costs, to the extent that necessities (products with income elasticities less than one) become a decreasing share of household expenditure and to the extent that necessities are subject to economies of scale.

Table 4.3 documents the results of the regression used to estimate the equivalence scales. The weight on children was estimated using the method in Creedy and Sleeman (2005a), using iterative estimation of the regression in Table 4.3 with varying weights for children and selecting the weight that produces the highest r-squared value (see Figure 4.1).

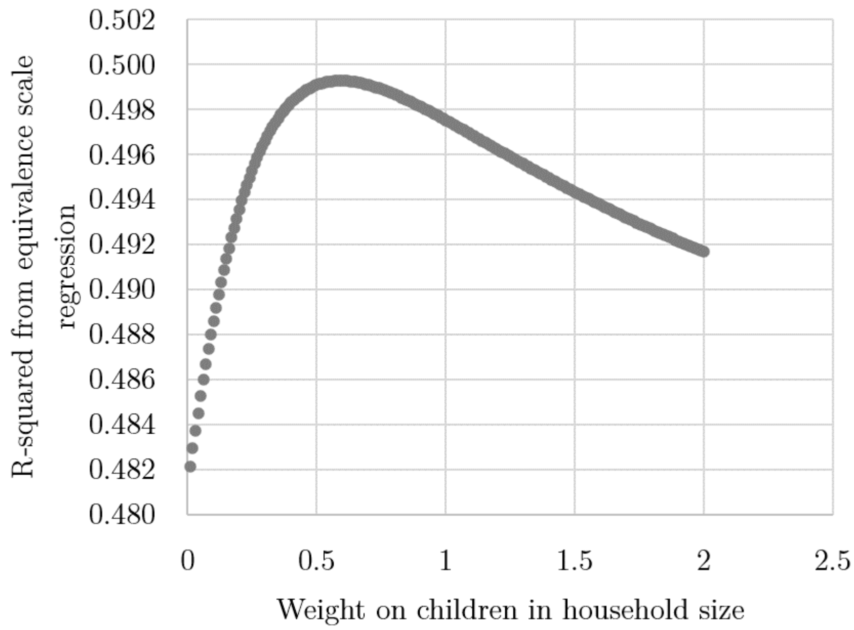

Figure 4.1: R-squared from iterated household expenditure regression with varying weights on children

4.2 Results of demand system estimation

Model parameter estimates for the baseline AIDS and QUAIDS models, with homogeneity and symmetry restrictions, are set out in full in appendix C.2. The models contain several hundred parameters, hence they have been relegated to the appendix.

Here the focus is on the estimated demand elasticities for the main QUAIDS and AIDS models. Model fit and parameter estimates are discussed further in section 4.3 in the context of tests of model restrictions and alternative model specifications.

4.2.1 Fitted expenditure and own-price elasticities of demand

Expenditure and own-price elasticities for the QUAIDS and AIDS models are summarised in Table 4.4 and Table 4.5. These elasticities are evaluated at sample means for expenditure shares, demographics and total expenditure.

All expenditure elasticities are significant and have magnitudes that accord with intuition in terms of whether products are considered expenditures are necessities or luxuries. Accommodation, communications, electricity, groceries and transport are all estimated to be necessities with expenditure shares declining as total expenditure increases (expenditure elasticities less than one). Expenditure on all other product groups rises at rates equal to or larger than growth in total expenditure. Electricity is estimated to have the smallest expenditure elasticity at 0.37 in both the AIDS and QUAIDS model.

The estimated uncompensated and compensated own-price elasticities have the expected signs, with three exceptions. Demand for alcohol and tobacco products and demand for education have own-price elasticities that are positive in both the QUAIDS model and the AIDS model. The AIDS model also has positive own-price elasticities for transport but the estimates are very close to and not statistically significantly different from zero.

The existence of a positive uncompensated or ordinary price elasticity of demand could be interpreted as education and alcohol being status goods, where consumption increases as prices increase, or as goods for which unobserved quality rises with price. This is certainly intuitively reasonable in the case of education.

The presence of positive compensated price elasticities does, however, represent a violation of underlying model theory.

In the case of education this is almost certainly due to empirical misspecification such as a failure to control for unobserved variation in product quality. Furthermore for large numbers of households consumption of education is unobserved in expenditure data because education is heavily subsidised. Of course the same is true of other expenditures, such as health. However, in the case of education these subsidies vary considerably in size according to level of education, life cycle of households and by income with substantial differences in prices for private versus public primary and secondary education.[5]

In the case of demand for alcohol and tobacco there are two likely sources of model misspecification. The first is that the model does not explicitly distinguish be-

[5]Transport is somewhat similar, on a smaller scale, in the sense that people aged sixty-five and over, comprising fifteen percent of the population, have had fully subsidised public transport outside peak travel hours since 2008. Hence some households will record very little spending on transport but may well be consuming larger unobserved amounts of public transport. This invariably means that consumer price indices for transport will be biased.

Table 4.4: QUAIDS model fitted shares, own-price and expenditure elasticities

	Mean expenditure shares:		Elasticities (standard errors):		
Product	Observed	Predicted	Expenditure	Uncompensated	Compensated
Acommodation	0.222	0.222	0.79***	-1.33***	-1.15***
			(0.09)	(0.13)	(0.15)
Air transport	0.017	0.018	2.08***	-0.98***	-0.94***
			(0.33)	(0.04)	(0.03)
Alcohol	0.028	0.028	1.15***	0.2***	0.23***
			(0.22)	(0.04)	(0.03)
Clothing	0.026	0.026	1.58***	-1.09***	-1.05***
			(0.23)	(0.04)	(0.02)
Communications	0.039	0.038	0.52***	-1.03***	-1.01***
			(0.11)	(0.02)	(0.03)
Contents	0.042	0.042	1.33***	-2.5***	-2.45***
			(0.16)	(0.04)	(0.03)
Education	0.011	0.012	0.95*	4.35***	4.36***
			(0.44)	(0.03)	(0.04)
Electricity	0.049	0.049	0.37***	-1.97***	-1.95***
			(0.08)	(0.05)	(0.06)
Groceries	0.148	0.147	0.58***	-0.95***	-0.87***
			(0.07)	(0.02)	(0.02)
Health	0.026	0.026	1.32***	-3.81***	-3.78***
			(0.22)	(0.05)	(0.03)
Insurance	0.051	0.051	1.15***	-0.76***	-0.7***
			(0.11)	(0.02)	(0.01)
Mortage interest	0.055	0.055	1.44***	-0.72***	-0.65***
			(0.24)	(0.02)	(0.04)
Other energy	0.006	0.006	0.89*	-0.5***	-0.5***
			(0.35)	(0.01)	(0.01)
Miscellaneous	0.069	0.070	1.43***	-0.84***	-0.74***
			(0.12)	(0.05)	(0.04)
Recreation	0.091	0.092	1.42***	-1.22***	-1.09***
			(0.1)	(0.06)	(0.04)
Eating out	0.042	0.041	1.43***	-0.58***	-0.52***
			(0.14)	(0.04)	(0.03)
Transport	0.078	0.076	0.77***	-0.17***	-0.12***
			(0.11)	(0.04)	(0.03)

Elasticities evaluated at sample means. *p<0.05, **p<0.01, ***p<0.001

Table 4.5: AIDS model fitted shares, own-price and expenditure elasticities

	Mean expenditure shares:		Elasticities (standard errors):		
Product	Observed	Predicted	Expenditure	Uncompensated	Compensated
Acommodation	0.222	0.222	0.79***	-0.58*	-0.4
			(0.02)	(0.24)	(0.24)
Air transport	0.017	0.018	2.08***	-0.96	-0.92
			(0.09)	(0.58)	(0.58)
Alcohol	0.028	0.028	1.14***	0.29	0.32
			(0.06)	(0.77)	(0.77)
Clothing	0.026	0.026	1.58***	-1.01	-0.97
			(0.06)	(0.92)	(0.92)
Communications	0.039	0.038	0.52***	-0.96***	-0.94***
			(0.03)	(0.22)	(0.22)
Contents	0.042	0.042	1.33***	-2.4***	-2.35***
			(0.04)	(0.41)	(0.41)
Education	0.011	0.012	0.94***	4.33*	4.34*
			(0.12)	(1.93)	(1.93)
Electricity	0.049	0.049	0.37***	-1.21***	-1.19***
			(0.02)	(0.15)	(0.15)
Groceries	0.148	0.148	0.58***	-0.82***	-0.74***
			(0.02)	(0.06)	(0.06)
Health	0.026	0.026	1.32***	-3.62**	-3.58**
			(0.06)	(1.26)	(1.26)
Insurance	0.051	0.051	1.14***	-0.72	-0.66
			(0.03)	(0.43)	(0.43)
Mortage interest	0.055	0.055	1.45***	-0.73*	-0.65
			(0.06)	(0.35)	(0.35)
Other energy	0.006	0.006	0.89***	-0.37	-0.37
			(0.08)	(1.06)	(1.06)
Miscellaneous	0.069	0.070	1.43***	-0.66**	-0.56*
			(0.03)	(0.23)	(0.23)
Recreation	0.091	0.092	1.42***	-1.09*	-0.96
			(0.03)	(0.5)	(0.5)
Eating out	0.042	0.041	1.42***	-0.32	-0.26
			(0.04)	(1.04)	(1.04)
Transport	0.078	0.076	0.77***	0.02	0.07
			(0.03)	(0.12)	(0.12)

Elasticities evaluated at sample means. *p<0.05, **p<0.01, ***p<0.001

tween smoking and non-smoking households. The second is biased price measurement, whereby expenditure weights used to reflect average spending across all consumers substantially understate price changes for smoking households and substantially overstate price changes for the majority of households that are non-smoking. On average, alcohol prices grew by less than overall inflation between 2007 and 2019. Beer prices grew by 1.9 percent each year, on average, and wine prices grew by 0.2 percent per year. Over the same period excise taxes on tobacco products grew significantly and consumer prices for tobacco products increased 8 percent per year on average, more than four times the average annual rate of consumer price inflation. The QUAIDS model produces own-price elasticities of demand that are on average 25 percent larger, in absolute terms, than the AIDS model. The uncompensated own-price elasticity of demand for electricity is, for example, -1.97 in the QUAIDS model and -1.21 in the AIDS model. The only case where demand is more price sensitive in the AIDS model is expenditure on mortgage interest.

The expenditure elasticities estimated with the QUAIDS and AIDS models are almost identical when evaluated at the mean of the model sample. However, evaluation of the expenditure elasticities at the sample mean obscures the central difference between the two models: the fact that the QUAIDS model admits income effects that are non-linear and thus expenditure elasticities that imply that products can be necessities at one income level and luxuries at another.

Table 4.6 provides an illustration of the variation in expenditure elasticities by total expenditure. This is based on analytical analysis using the coefficients in Table C.3, evaluating expenditure elasticities at mean expenditure shares and holding demographic differences constant.

Alcohol and tobacco is a luxury at most income levels, with an expenditure elasticity of 1.4, but a necessity at high income levels with an expenditure elasticity of 0.86. Education is a necessity at low income levels, with an expenditure elasticity of 0.50, but on average has an expenditure elasticity close to 1.0 and at high income levels has an expenditure elasticity close to 1.5. Transport is necessity at most income levels but a luxury at very low income levels.

Electricity is a necessity at all income levels although expenditure elasticities are an increasing function of income. That is, electricity expenditure is a declining share of total expenditure for all households but the rate of decline slows as incomes increase,

Table 4.6: Expenditure elasticities by total expenditure

Product	Total expenditure: Lower quintile	Mean	Upper quintile
Electricity	0.00	0.37	0.74
Communications	0.46	0.52	0.62
Groceries	0.71	0.58	0.50
Transport	1.06	0.77	0.53
Acommodation	0.52	0.79	0.97
Other energy	0.74	0.89	1.05
Education	0.45	0.95	1.46
Insurance	1.28	1.15	1.05
Alcohol	1.41	1.15	0.86
Health	1.52	1.32	1.11
Contents	1.48	1.33	1.18
Recreation	1.53	1.42	1.33
Eating out	1.62	1.43	1.26
Mortage interest	1.20	1.44	1.65
Clothing	1.60	1.58	1.44
Air transport	1.89	2.08	2.19

Evaluated at mean expenditure share and mean household size

as can be seen from the positive coefficient for λ_i for electricity, labelled *elec*, in Table C.3.

Expenditure on other non-electricity energy products also rises with income and is a necessity at low income levels but rises to being unit elastic at higher income levels.

In contrast food expenditure, which is a necessity at all income levels, has expenditure elasticities that decline as income increases.

4.2.2 Cross-price and substitution elasticities

Tables 4.7 and 4.8 present uncompensated own and cross-price elasticities for the QUAIDS and AIDS models, evaluated at sample means.[6] Many of the estimated cross-price elasticities are imprecise, in the sense that they have large standard errors and are not significantly different from zero. For example, only seven out of sixteen cross-price elasticities for electricity are significantly different from zero at the five percent level.

Interestingly the cross-price elasticity between electricity and other energy is small negative in the QUAIDS model (-0.05), indicating these products are substitutes, but small positive, indicating complements, in the AIDS model. The former makes more sense intuitively, although in both cases the elasticity is not statistically significantly different from zero.

[6]Tables of compensated cross-price elasticities are in Tables C.5 and C.6 in appendix C.4.

Table 4.7: QUAIDS model uncompensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-1.33**	**0.22**	**0.31**	**-0.11**	**-0.23**	**0.29**	-0.07	**-0.28**	**-0.40**	-0.07	-0.01	0.09	**0.37**	**-0.27**	**0.23**	**0.33**	-0.05
air	2.71	**-0.98**	**1.94**	**-1.32**	**-1.44**	**1.31**	**-1.88**	**-1.97**	0.35	-0.37	**-1.46**	**-0.37**	**-1.47**	**1.02**	**-0.10**	**3.26**	-0.24
alc	2.49	**1.26**	**0.20**	**0.34**	**0.78**	**-1.53**	**-1.06**	**-0.90**	0.06	**0.57**	**1.96**	**0.08**	-0.52	**0.87**	**-1.07**	**-3.27**	**-1.27**
cloth	-0.95	**-0.92**	**0.36**	**-1.09**	**0.83**	0.22	**-0.87**	**1.21**	0.03	-0.01	**3.35**	**0.25**	0.12	**0.72**	**0.34**	**-3.55**	**-1.05**
comm	-1.34	**-0.67**	**0.55**	**0.55**	**-1.03**	**0.29**	**-0.84**	**-0.08**	**0.56**	**0.17**	**-0.61**	**-0.18**	0.16	**-0.43**	**0.36**	**0.93**	**0.60**
cont	1.53	**0.56**	**-1.02**	**0.14**	**0.27**	**-2.50**	**1.10**	**0.61**	**-0.55**	0.27	**-0.91**	**0.62**	**-0.89**	**0.88**	**-0.19**	**-0.90**	-0.03
take	-0.40	**-0.83**	**-0.72**	**-0.55**	**-0.80**	**1.13**	**-0.58**	**-0.50**	**1.50**	-0.04	**-0.74**	**0.23**	-0.28	0.44	**-0.58**	**1.75**	-0.03
educ	-5.98	**-3.35**	**-2.35**	**2.95**	-0.27	**2.40**	**-1.91**	**4.35**	**3.17**	-0.24	**-2.07**	**2.43**	-0.63	1.07	**0.73**	-2.50	1.19
elec	-1.80	0.13	0.03	0.01	**0.44**	**-0.46**	**1.23**	**0.67**	**-1.97**	**0.25**	**0.67**	0.01	0.58	**-1.07**	-0.05	-0.06	0.38
food	-0.11	**-0.05**	**0.11**	0.00	0.04	**0.08**	-0.01	-0.02	0.08	**-0.95**	**-0.09**	**-0.02**	-0.05	-0.02	**0.02**	0.02	-0.04
hlth	-0.10	**-0.97**	**2.01**	**3.19**	**-0.88**	**-1.40**	**-1.11**	**-0.81**	**1.24**	**-0.46**	**-3.81**	**-1.66**	**0.80**	0.21	**0.12**	**2.36**	0.27
insur	0.38	**-0.13**	0.04	**0.12**	-0.13	**0.49**	**0.18**	**0.49**	0.00	-0.06	**-0.86**	**-0.76**	**-0.57**	0.17	**-0.10**	-0.16	-0.12
othr	1.19	**-0.38**	**-0.21**	**0.05**	0.09	**-0.53**	**-0.16**	-0.10	**0.42**	-0.11	**0.31**	**-0.43**	**-0.84**	0.14	**0.11**	-0.06	**-0.47**
mort	-0.89	**0.34**	**0.39**	**0.32**	**-0.29**	**0.62**	**0.26**	**0.24**	**-0.87**	**-0.19**	0.04	0.11	0.07	**-0.72**	**-0.29**	-0.27	-0.31
nrg	8.27	-0.29	**-4.85**	**1.44**	**2.25**	-1.30	**-3.87**	**1.26**	-0.40	0.43	0.55	-0.85	1.19	**-2.57**	**-0.50**	-2.99	1.23
rec	0.80	**0.64**	**-0.99**	**-1.00**	**0.39**	**-0.41**	**0.78**	**-0.29**	-0.03	0.04	**0.70**	**-0.09**	-0.05	-0.08	**-0.20**	**-1.22**	0.01
trans	-0.14	**-0.06**	**-0.47**	**-0.36**	**0.31**	-0.02	-0.02	**0.17**	0.26	-0.07	**0.10**	**-0.08**	**-0.44**	-0.11	**0.10**	0.01	**-0.17**

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table 4.8: AIDS model uncompensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-0.58**	0.19	0.22	-0.17	-0.13	0.17	-0.20	-0.23	-0.06	-0.07	-0.11	0.03	0.18	-0.17	**0.25**	0.12	**-0.21**
air	2.01	-0.96	**2.00**	**-1.31**	**-1.54**	**1.31**	**-1.86**	**-1.95**	0.13	**-0.64**	**-1.45**	-0.36	**-1.39**	0.95	-0.10	**3.36**	-0.27
alc	1.67	**1.31**	0.29	0.42	0.64	**-1.36**	-0.84	-1.01	-0.38	**0.59**	**2.12**	0.13	-0.29	0.77	**-1.11**	**-3.03**	**-1.06**
cloth	-1.63	**-0.90**	0.44	-1.01	0.70	0.33	-0.73	1.15	-0.38	-0.14	**3.45**	0.25	0.29	0.65	0.32	**-3.41**	**-0.95**
comm	-0.71	**-0.69**	0.48	0.50	**-0.96**	0.23	**-0.92**	-0.07	**0.81**	**0.27**	**-0.67**	-0.18	0.02	-0.34	**0.37**	0.82	**0.52**
cont	0.81	**0.58**	**-0.92**	0.21	0.19	**-2.40**	**1.24**	0.58	**-0.89**	0.23	**-0.81**	0.63	**-0.70**	**0.78**	-0.21	-0.74	0.11
take	-1.25	**-0.81**	-0.58	-0.46	**-0.91**	**1.26**	-0.32	-0.59	**1.04**	-0.12	-0.55	0.19	-0.05	0.32	-0.65	**1.93**	0.13
educ	-4.95	**-3.30**	-2.63	2.81	-0.27	2.28	-2.24	**4.33**	**3.58**	-0.29	-2.28	2.56	-0.94	1.31	0.81	-2.63	0.91
elec	-0.17	0.08	-0.19	-0.16	**0.64**	**-0.70**	**0.89**	**0.77**	**-1.21**	**0.32**	**0.43**	0.00	0.15	**-0.84**	0.01	-0.41	0.04
food	-0.06	-0.05	**0.13**	0.00	**0.07**	**0.10**	0.00	-0.02	**0.10**	**-0.82**	**-0.07**	0.00	-0.03	-0.03	0.02	0.05	0.03
hlth	-1.02	**-0.96**	**2.17**	**3.30**	**-0.99**	**-1.25**	-0.83	-0.90	**0.75**	**-0.50**	**-3.62**	**-1.70**	**1.06**	0.06	0.06	**2.56**	0.48
insur	0.06	-0.11	0.07	0.13	-0.16	0.51	0.16	0.52	-0.04	-0.07	**-0.87**	-0.72	**-0.51**	0.13	-0.09	-0.08	-0.07
othr	0.43	**-0.35**	-0.12	0.11	-0.02	**-0.43**	-0.03	-0.15	0.06	-0.19	**0.41**	**-0.40**	**-0.66**	0.05	0.08	0.12	**-0.34**
mort	-0.87	0.33	0.40	0.32	-0.29	**0.61**	0.24	0.26	**-0.85**	-0.21	0.03	0.11	0.07	**-0.73**	**-0.29**	-0.28	-0.32
nrg	**8.88**	-0.28	**-5.02**	1.37	**2.30**	-1.43	-4.27	1.40	0.01	0.43	0.27	-0.71	0.99	**-2.42**	-0.37	-3.12	1.07
rec	0.16	**0.67**	**-0.93**	**-0.96**	0.31	-0.34	**0.86**	-0.31	-0.28	-0.04	**0.76**	-0.06	0.09	-0.16	-0.21	**-1.09**	0.10
trans	**-0.64**	-0.04	**-0.38**	**-0.31**	**0.26**	0.09	0.10	0.13	0.01	0.04	0.19	-0.03	**-0.27**	-0.19	0.09	0.18	0.02

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

4.2.3 Variance in electricity elasticities across households

The models show wide ranging price elasticities of demand for electricity and the range of elasticities in the QUAIDS model is much wider than for the AIDS model. This is illustrated in Figure 4.2 which depicts densities for estimated uncompensated price elasticities of demand resulting from the AIDS and the QUAIDS models.[7]

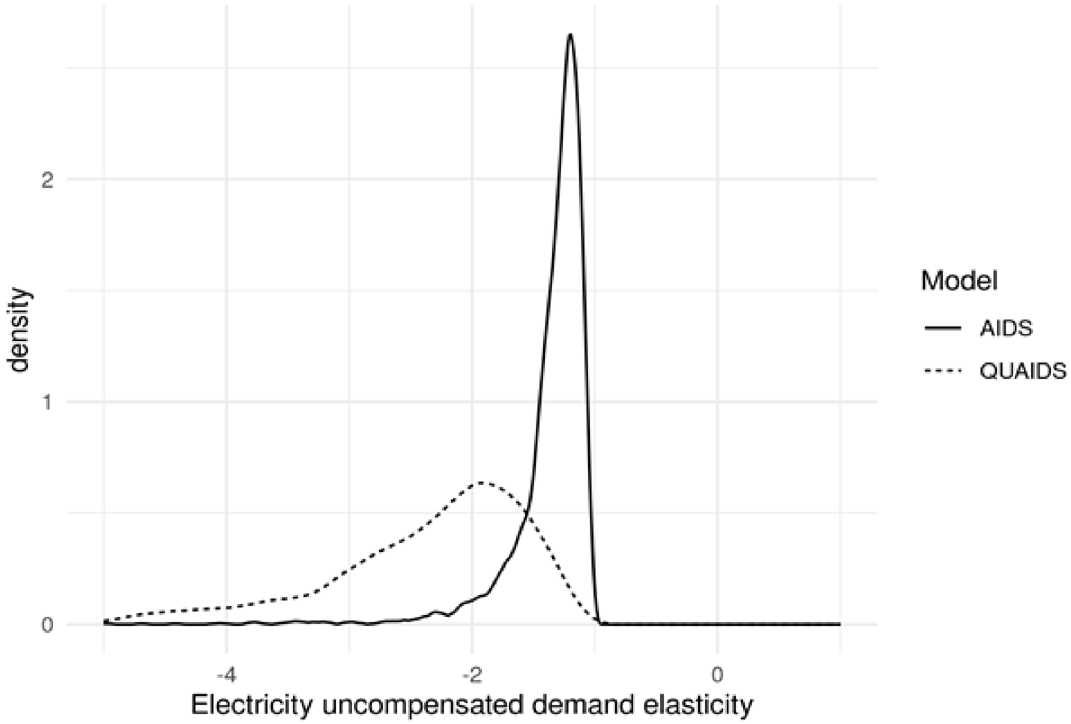

Figure 4.2: Electricity, own-price uncompensated elasticities, sensitivity to model specification. Kernel densities fitted to elasticities over a random sample of 3,000 households.

The result shown in Figure 4.2 is commodity-specific, rather than a general result applying to all commodity groups. That is, the QUAIDS model does not consistently produce a wider distribution of estimated price elasticities of demand. For example, the QUAIDS model produces demand elasticities for groceries (mainly food) with a narrower distribution than for the AIDS model (see Figure 4.3). For a majority of commodity groups the distributions are very similar (see Figures in Appendix C.3).

[7]Densities have been fitted over a random sample of 3,000 households, because the iterative calculation of individual demand elasticities was computationally very time consuming. All fitted densities shown in this thesis have been calculated using the same random sample.

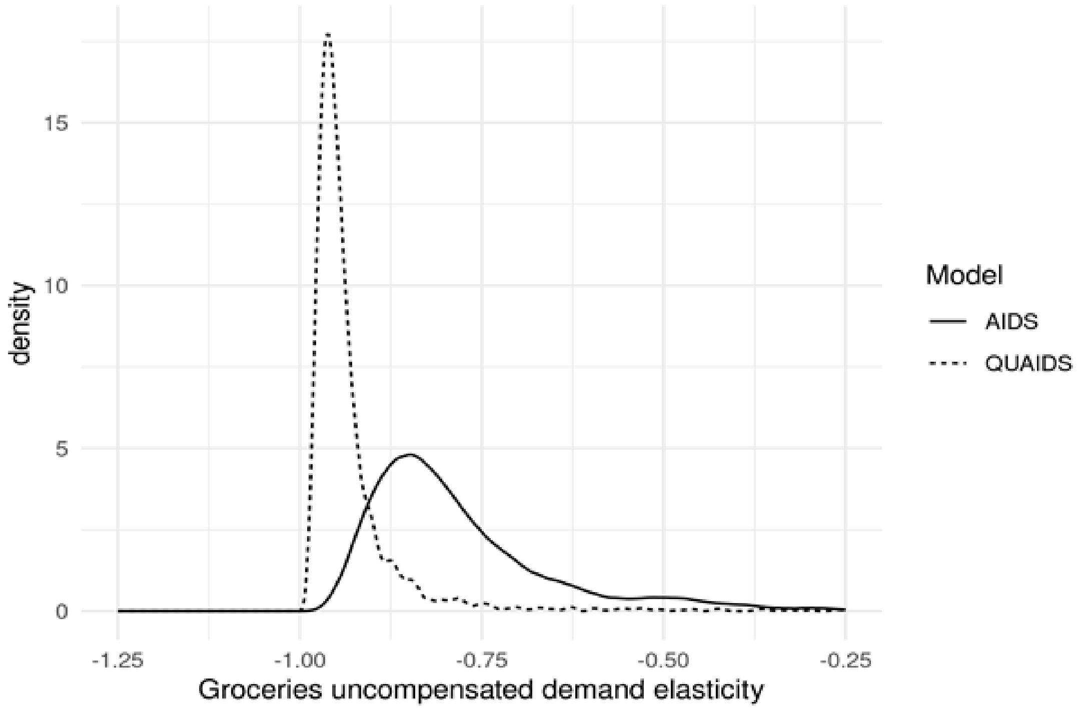

Figure 4.3: Electricity, own-price uncompensated elasticities, sensitivity to model specification. Kernel densities fitted to elasticities from a random sample of 3,000 households.

4.2.4 Comparison of elasticities with other research

Estimated sensitivity of households to changes in prices can have a significant effect on estimates of the effects on households of changes in product prices. Generally speaking, the larger the compensated price elasticity the larger the effect on welfare of a price increase, other things being equal.

The estimated own-price uncompensated demand elasticities for electricity are large, in absolute terms, relative to elasticities cited internationally. This is partly, but only partly, because the model does not control for year fixed effects and thus the elasticities must be interpreted as longer run effects. In a recent survey of residential electricity price elasticities of demand Zhu *et al.* (2018) report mean short run elasticities of -0.2 and mean long-run elasticities -0.60.[8] Long-run elasticities range from -4.2 to 0.60.

[8]This meta-analysis is a useful collation of prior studies but the observations in the paper are of questionable quality, such as an observation that distribution of elasticity estimates are approximately normally distributed, when visual inspection of these elasticities does not confirm this observation.

There are no strictly comparable estimates for electricity demand in New Zealand, however the elasticity estimates found here are not entirely out of line with approximately comparable New Zealand estimates. For example, Thomas (2019) finds that household demand for utilities, communication and education is highly price inelastic, with an own-price elasticity of -1.6. Thomas used a QUAIDS model HES expenditure data for the 2007, 2010, 2013 and 2016 surveys. However Thomas's method included only 9 product groups and included a larger number of demographic predictors than are used here.

Experimental analysis by the NZ Institute of Economic Research (NZIER, 2020) found an uncompensated own-price elasticity of demand of -4.12 on average nationally and -6.10 in major urban areas. The NZ Institute of Economic Research's model was a linear approximation to the AIDS model and used HES data augmented by detailed regional survey data on prices provided by Stats NZ.

One reason for the higher long run own-price elasticities of demand estimated here is the use of demand system estimation and downward bias in elasticity estimation in other models. Labandeira, Labeaga, and López-Otero (2017) conducted a meta-analysis of energy demand studies internationally and found that demand systems produced more elastic price elasticities than single equation models and that long term elasticities are around three times larger, in absolute terms, than short term price elasticities.

A meta-analysis of 419 meat demand studies showed a similar result in terms of demand system elasticities being more elastic than other demand models. Gallet (2010) reports a median price elasticity for meat of -0.77 with a standard deviation 1.28 and the analysis shows that QUAIDS systems tend to result in own-price elasticities for meat that are more elastic than simple linear demand models and than AIDS models.

A key reason for differences in elasticities between micro-level demand systems and more aggregated models is that aggregate models average over heterogeneous prices and heterogeneous household characteristics. By way of example, when the QUAIDS model estimated here was used to estimate demand after a change to the structure of electricity prices (see chapter 5), with prices increasing for some households and

Furthermore, there is no strong reason to believe that elasticity estimates would naturally tend towards a normal distribution as the estimates come from such vastly different contexts and use vastly different data sets and models that it does not follow that the estimates are measuring the same thing at all.

decreasing for others, the mean ex-post observed uncompensated own-price elasticity of demand across household types and income quintiles was -0.20 even though the modelling was based on a model with much larger mean individual elasticities.

Studies of consumer demand based on demand systems do not generally include a distinction between short-run and long-run effects, as the analyses typically do not have a dynamic structure. Rather demand system elasticities are identified as being short-run or long-run based on the data used. Nonetheless, we can observe that, our estimates of highly inelastic demand for electricity implies inelastic demand in the short run, based on the general meta-analysis finding that long-run elasticities are on average three times larger than short-run elasticities.

Filippini (1995) investigated price elasticities of residential peak and off-peak electricity demand in Switzerland using an almost ideal demand system, restricted to electricity consumption. The results of this analysis showed own-price elasticities of demand between -1.29 and -1.50 for peak demand and -2.36 and -2.42 for off-peak demands.[9]. In a related study Filippini (2011) estimated a dynamic panel to investigate differences in short-run and long-run price elasticities of residential peak and off-peak electricity demand in Switzerland and found long-run elasticities that ranged from -1.60 and -2.26 for peak demand and -1.27 and -1.65 for off-peak demand.

Thorsnes *et al.* (2012) report on a 20 month time-of-use pricing experiment in New Zealand in which they found price sensitivity to electricity prices to be conditional on the time of year, with consumption being unresponsive to prices during summer months but price responsive during colder winter months when electricity bills are typically highest. The study indicated a mean peak period price elasticity of demand of -0.371 (standard error 0.074) and an off-peak price elasticity of demand of -0.0902 (not statistically significant in light of a standard error 0.077). These estimates hold few implications for this study because the study was short-lived.[10]

Baker and Blundell (1991) found the short-run price elasticity of electricity demand in the UK in the 1980s to be more elastic in the summer (-1.03 on average) than the winter (-0.67) and that home owners with mortgages exhibited more elastic demand (-1.04) than those without mortgages (-0.87) or renting (-0.94). This study used micro-

[9]The ranges in these estimates come from two different models, one with homogeneity restrictions and one without homogeneity restrictions

[10]The authors also point out that their study is not representative of the New Zealand population.

data, a modified form of the AIDS model and controls for the availability of selected energy-using appliances or facilities such as central heating.

Gomez-Lobo (1996) estimated a QUAIDS model of consumer demand in the UK using similar data to Baker and Blundell (1991), but with a data set that spanned 1985 to 1993. The study estimated short-run own-price uncompensated demand elasticities for electricity of -0.56.

Schulte and Heindl (2017) find own-price elasticities of -0.40, on average, for Germany based on a quadratic expenditure system (QES). This excludes space heating because in Germany this is typically based on gas, oil or district heating. The estimated own-price elasticity of demand for space heating is -0.50.

There is of course no reason why an elasticity estimated for one country should be the same as the elasticity for another country. Krishnamurthy and Kriström (2015) investigate household electricity demand across 11 OECD countries and find wide variation in price and income elasticities - despite the use of a single consistent methodology.[11] This study finds own-price elasticities of demand ranging from -0.27 for South Korea and -1.4 for Australia.

Even within the same country there are a wide range of estimates of price elasticities of demand, based on model variations. Fell, Li, and Paul (2014) estimated a model of residential electricity demand for the United States and found a short-run price elasticity of demand of -0.50, on average, and noted that this was significantly above some estimates and significantly below others (plus or minus 0.25, approximately). The differences appear to be related to when data was sampled, estimation methodology, model functional form and geographic scope. The study most similar to Fell *et al.* (2014) found a short-run price elasticity of demand of -0.74 and a long-run price elasticity of demand of -0.814 (Alberini, Gans, and Velez-Lopez, 2011).

Furthermore many of these studies for which elasticities have been estimated are focussed on understanding the impacts of time of use pricing. Studies of time of use pricing are invariably focussed on short term demand response, typically monthly or weekly. This is reflects an interest in demand management and the efficiency of short term variations in prices. The implications for sustained adaptation to price changes is unclear.

[11] A double-log model with sensitivity testing using a translog model.

Few studies explore heterogeneity in price responsiveness across households. Those that do show considerable heterogeneity. For example Reiss and White (2005) showed that households' appliance portfolios had a significant effect on measured demand response in California. One implication of this was that a large amount of measured demand response came from a small number of households. The study also showed that the relationship between income and price sensitivity followed an inverted u-shape with demand responsiveness largest at low and high incomes. Similarly, Romero-Jordán, del Río, and Peñasco (2016) found that low-income households are likely to be more sensitive to price changes, due to binding income constraints, while high-income households are likely to be less price sensitive.

That said, positive correlations between price elasticities of demand and incomes are by no means guaranteed. It is conceptually possible that, at least at some levels of income, electricity could be an inferior good. It is also possible conceptually that higher-income households have less binding budget constraints or higher rates of saving that allow for investment in energy-saving devices so that if prices rise significantly their energy consumption could fall. And own-production could increase for higher-income households, if they are more willing and able to invest in solar panels, for example, which would cause measured demand for electricity to appear more price responsive at higher incomes. Indeed such an effect would be bolstered by sorting effects with higher income or higher wealth households congregating in areas more conducive to self-production (such as in Nelson in the New Zealand context).

On balance, the elasticities estimated with QUAIDS and AIDS models are high by international comparison, but not excessively so for longer run elasticities.

4.3 Sensitivity to model specification

The estimated models are sensitive to model specification, however the core QUAIDS and AIDS models discussed above and used in the welfare evaluation in Chapter 5 do not exhibit extreme parameter values relative to the other model specifications that have been tested.

Model restriction tests raise question marks over the consistency of the empirical models with underlying consumer demand theory. However, the model restrictions do not have large effects on the model parameter estimates or elasticities.

4.3.1 Tests of restrictions

Tests of the theoretical restrictions in the model have been conducted using likelihood ratio tests comparing pairs of models with and without restrictions. The results of these tests are summarised in Table 4.9. First we compare the core models, including homogeneity ($\sum_j \gamma_{ij} = 0 \ \forall i$) and symmetry ($\gamma_i j = \gamma_j i$) restrictions, with versions of the models which drop the symmetry restrictions. Comparison of these models suggests rejection of the symmetry restrictions in both the QUAIDS and the AIDS models ($p = 0.000$ in both cases).

Comparison of unrestricted models with the models with homogeneity restrictions, but no symmetry restrictions, indicate that homogeneity improves the model. That is, under the likelihood ratio test we cannot reject the hypothesis of homogeneity against the alternative of no restrictions in either the QUAIDS model ($p = 0.274$) or the AIDS model ($p = 0.135$).

The test of joint symmetry and homogeneity against an unrestricted model further suggests that the symmetry conditions do not improve the model.

Table 4.9: Tests of model restrictions

r^2	Model restrictions	Parameters	Log-likelihood	χ^2	$p\,(< \chi^2)$
		QUAIDS model			
0.459	Homogenity and symmetry	400	393,366		
0.463	Homogeneity	520	393,671	611.81	0.000
0.463	Unrestricted	536	393,681	18.90	0.274
0.459	Homogenity and symmetry	400	393,366	630.70	0.000
		AIDS model			
0.455	Homogenity and symmetry	384	392,585		
0.459	Homogeneity	504	392,894	619.07	0.000
0.459	Unrestricted	520	392,905	22.25	0.135
0.455	Homogenity and symmetry	384	392,585	641.32	0.000

So, overall, symmetry restrictions are rejected. This means the data is not consistent with the underlying theoretical models being estimated. This is important in the sense that welfare analysis follows from the underlying theoretical conditions, specifically that the slutsky matrix of substitution elasticities is negative semi-definite with symmetric off-diagonal parameters (the $\gamma_i j = \gamma_j i$) and negative diagonal entries ($\gamma_i i < 0, \forall i$).

Rejection of symmetry restrictions appears to be a common finding in empirical estimation of demand systems (Deaton and Muellbauer, 1980; Gomez-Lobo, 1996). Although most articles do not report tests of model restrictions, of the papers reviewed in this study that do test model restrictions only one did not show rejection of the symmetry restrictions and that was Banks *et al.* (1997) where the sample data included only a single type of household.

This raises a question about what, if anything, to do about welfare analysis when the model is inconsistent with consumer demand theory. It appears that there is no guidance on this in the literature. The approach taken here is to ignore these inconsistencies and to rely primarily on the model that includes symmetry restrictions, to adhere to theoretical propositions over empirical estimation, and to ignore the problem of negative own-price compensated elasticities of demand for alcohol and education on the grounds that these are not products of primary interest in this study.

The decision to rely on the fully restricted model is justified on the grounds that the model parameters are not substantially different from parameters of the model estimated with homogeneity but without symmetry restrictions, as below in Table 4.10 and Table 4.11.

4.3.2 Results from alternative QUAIDS models

The alternative QUAIDS models that have been estimated show substantial sensitivity in model results to changes in model specification. As discussed in section 4.1, the alternative models estimated include: a model with four regional dummies; a model estimated on a sub-sample of the data using only the surveys from 2013, 2016 and 2019; a model with. In addition, in the tables below, the results for the core model without symmetry restrictions is shown alongside the core model results with both symmetry and homogeneity restrictions.

The expenditure elasticities vary very little across different model specifications.

This is shown in Table 4.10. Price elasticities, however, vary quite considerably across the five models shown in Table 4.11.

In terms of the key product of interest, compensated own-price elasticities for electricity range from -1.19 in the model that adds number of adults and number of children as explanatory variables to -2.69 for the model estimated on the survey sub-sample (2013-2019). This is substantial variation, although the results consistently point to own-price elasticities that are high relative international averages.

The model with adults and children as explanatory variables causes substantial changes in elasticities where expenditure is related to necessities that are likely to scale most linearly by household size, such as eating out and accommodation. Although this is not universally true in the sense that the own-price elasticity on grocery demand changes very little.

The model with regional dummies has surprisingly little effect on electricity elasticities, with the compensated own-price elasticity of demand declining from -1.95 in the core model to -1.88 in the model with regional dummies. This provides some confidence that the core model is reasonable, with respect to estimates of electricity elasticities. That said, the compensated own-price elasticity for other energy products changes significantly with the use of regional dummies. This likely reflects the availability and quality of gas products which varies significantly by region with reticulated gas only available in the North Island, albeit not everywhere in the North Island.

4.3.3 Comparison with a linear expenditure system

Estimation of a linear expenditure system shows substantial differences in expenditure and price elasticities for electricity as compared to the almost ideal demand systems. This is summarised in the Table 4.12 below. Here the parameters of the demand system have been estimated on a reduced form product-by-product (i) and household-by-household (h) basis using linear ordinary least squares and the following equation (Creedy, 2004, p. 80):

$$w_{ih} = \delta_1 + \delta_2 \ln(\mu_h) + \frac{\delta_3}{\mu_h} \tag{4.2}$$

where w_{ih} is expenditure share and μ_h is total expenditure.

Elasticities are calculated using (Creedy, 2004, p. 80):

$$e_i = 1 + \frac{(\mu/\delta_3)\,\delta_2 - 1}{(\mu/\delta_3)\,(\delta_1 + \delta_2 \ln \mu) + 1} \tag{4.3}$$

$$e_{ij} = -e_i w_i \left(1 + \frac{e_j}{\xi}\right) \tag{4.4}$$

$$e_{ij} = e_i \left[\frac{1}{\xi} - w_i \left(1 + \frac{e_j}{\xi}\right)\right] \tag{4.5}$$

where e_i is the expenditure elasticity, e_ij is the cross-price elasticity, e_ii is the own-price elasticity, and ξ is the marginal utility of total expenditure (the Frisch parameter) which is set equal to -1.9 (Creedy, 2004, p. 81).

The results of the estimation show expenditure elasticities for electricity products that are substantially lower than for the almost ideal demand systems and elasticities. The almost ideal demand system elasticities are more in line with international estimates.

The elasticities in Table 4.12 include cross-price elasticities for a selection of other products and including a detailed breakdown for other energy products: gas, bottled gas, solid fuel, and other (non-transport) energy.

The LES model has been estimated on a sub-sample of the HES surveys, from 2007 to 2016, because the 2019 survey data was not available when this model was estimated. However it is extremely unlikely that the addition of the 2019 survey would substantially change the elasticity estimates, as far as comparison with the almost ideal demand systems are concerned.

Notably, the LES model, as estimated here, provides a poor fit to the data, excludes data on prices and has a restrictive functional form. For these reasons it is not considered for inclusion as a model for welfare evaluation in Chapter 5. Rather it is provided as a point of comparison given the history of LES models in demand analysis in New Zealand. Furthermore, it adds further evidence of the extent to which models of demand are sensitive to model specification choices.

Table 4.10: Comparisons of alternative models, expenditure elasticities

		Model variants:			
Product	QUAIDS	No symmetry	Regions	2013-2019	Adults and children
Acommodation	0.79***	0.76***	0.77***	0.78***	0.81***
	(0.09)	(0.09)	(0.09)	(0.11)	(0.09)
Air transport	2.08***	2.09***	2.07***	2.1***	2.03***
	(0.33)	(0.3)	(0.33)	(0.38)	(0.3)
Alcohol	1.15***	1.14***	1.15***	1.17***	0.99***
	(0.22)	(0.21)	(0.22)	(0.28)	(0.21)
Clothing	1.58***	1.6***	1.6***	1.55***	1.62***
	(0.23)	(0.22)	(0.23)	(0.29)	(0.22)
Communications	0.52***	0.54***	0.53***	0.51***	0.51***
	(0.11)	(0.1)	(0.11)	(0.13)	(0.1)
Contents	1.33***	1.33***	1.33***	1.32***	1.29***
	(0.16)	(0.15)	(0.16)	(0.2)	(0.15)
Education	0.95*	0.96*	0.95*	0.86	1.17**
	(0.44)	(0.4)	(0.44)	(0.53)	(0.4)
Electricity	0.37***	0.37***	0.37***	0.36***	0.36***
	(0.08)	(0.09)	(0.08)	(0.1)	(0.09)
Groceries	0.58***	0.58***	0.58***	0.59***	0.59***
	(0.07)	(0.07)	(0.07)	(0.09)	(0.07)
Health	1.32***	1.35***	1.35***	1.38***	1.29***
	(0.22)	(0.2)	(0.22)	(0.27)	(0.2)
Insurance	1.15***	1.15***	1.15***	1.14***	1.13***
	(0.11)	(0.11)	(0.11)	(0.13)	(0.11)
Mortage interest	1.44***	1.44***	1.43***	1.48***	1.62***
	(0.24)	(0.22)	(0.24)	(0.29)	(0.22)
Other energy	0.89*	0.89**	0.89**	1**	0.9**
	(0.35)	(0.3)	(0.35)	(0.38)	(0.3)
Miscellaneous	1.43***	1.44***	1.44***	1.44***	1.44***
	(0.12)	(0.11)	(0.12)	(0.15)	(0.11)
Recreation	1.42***	1.44***	1.44***	1.45***	1.4***
	(0.1)	(0.1)	(0.1)	(0.14)	(0.1)
Eating out	1.43***	1.42***	1.42***	1.36***	1.33***
	(0.14)	(0.13)	(0.14)	(0.17)	(0.13)
Transport	0.77***	0.78***	0.77***	0.78***	0.68***
	(0.11)	(0.1)	(0.11)	(0.14)	(0.1)

Elasticities evaluated at sample means. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 4.11: Comparisons of alternative models, compensated own-price elasticities

		Model variants:			
Product	QUAIDS	No symmetry	Regions	2013-2019	Adults and children
Acommodation	-1.15***	-1.97***	-0.91***	-1.44***	-0.36*
	(0.15)	(0.17)	(0.16)	(0.17)	(0.17)
Air transport	-0.94***	-0.69***	-1.13***	0.05	-0.84***
	(0.03)	(0.02)	(0.03)	(0.04)	(0.02)
Alcohol	0.23***	0.91***	-0.12***	-0.02	0.21***
	(0.03)	(0.02)	(0.03)	(0.04)	(0.02)
Clothing	-1.05***	-1.03***	-0.85***	-0.99***	-1.2***
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)
Communications	-1.01***	-1.09***	-1.03***	-1.16***	-0.9***
	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)
Contents	-2.45***	-3.2***	-2.8***	-2.67***	-2.28***
	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)
Education	4.36***	4.61***	4.26***	2.69***	4.98***
	(0.04)	(0.03)	(0.04)	(0.05)	(0.03)
Electricity	-1.95***	-2.06***	-1.88***	-2.69***	-1.19***
	(0.06)	(0.05)	(0.06)	(0.07)	(0.05)
Groceries	-0.87***	-0.82***	-0.83***	-0.93***	-0.9***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Health	-3.78***	0.08*	-5.49***	-3.7***	-3.74***
	(0.03)	(0.02)	(0.03)	(0.04)	(0.02)
Insurance	-0.7***	-1.31***	-0.69***	-0.3***	-0.62***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Mortage interest	-0.65***	0.18***	-0.74***	-1.34***	-0.56***
	(0.04)	(0.02)	(0.04)	(0.03)	(0.02)
Other energy	-0.5***	-0.12***	-0.99***	-0.09***	-0.1***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Miscellaneous	-0.74***	-0.65***	-0.74***	0.01	-0.38***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Recreation	-1.09***	-2.78***	-1***	0.49***	-0.85***
	(0.04)	(0.03)	(0.04)	(0.04)	(0.03)
Eating out	-0.52***	-1.45***	-0.98***	0.81***	-1.1***
	(0.03)	(0.02)	(0.03)	(0.04)	(0.02)
Transport	-0.12***	-0.29***	-0.13***	0.29***	0.02
	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)

Elasticities evaluated at sample means. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 4.12: Linear expenditure system: estimated electricity elasticities

Household	Own price	Expenditure	Gas	Bottled gas	Solid fuel	Other energy	Food	Housing
65+ single	-0.39	0.71	-0.02	-0.01	-0.02	-0.03	-0.02	-0.02
Single - no children	-0.30	0.54	-0.02	0.00	-0.02	-0.04	0.03	0.01
Single - 1 child	-0.26	0.46	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01
Single - 2 children	-0.22	0.39	-0.01	0.00	-0.01	0.02	-0.02	-0.02
Single - 3 children	-0.18	0.33	-0.03	-0.02	0.00	-0.07	-0.02	-0.02
Single - 4+ children	-0.32	0.58	-0.02	-0.04	0.00	-0.08	-0.01	0.10
65+ couple	-0.40	0.73	-0.01	-0.01	-0.01	-0.03	-0.02	-0.02
Couple - no children	-0.33	0.60	-0.01	-0.01	-0.01	0.00	-0.01	-0.02
Couple - 1 child	-0.33	0.61	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01
Couple - 2 children	-0.29	0.53	-0.01	-0.02	-0.01	-0.01	-0.02	-0.02
Couple - 3 children	-0.34	0.62	-0.02	-0.01	-0.02	-0.02	-0.02	-0.02
Couple - 4+ children	-0.22	0.40	0.00	-0.01	-0.01	-0.02	-0.02	-0.02
3 adults - no children	-0.33	0.60	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02
3 adults - 1 child	-0.32	0.59	-0.01	-0.01	-0.10	0.01	-0.02	-0.02
3 adults - 2+ children	-0.32	0.58	-0.01	-0.02	0.00	0.01	-0.02	-0.02
4+ adults - no children	-0.34	0.63	-0.01	-0.01	-0.01	-0.01	-0.02	-0.01
4+ adults - 1 child	-0.19	0.34	-0.03	0.11	0.00	-0.05	-0.01	-0.01
4+ adults - 2+ children	-0.34	0.61	0.00	0.00	-0.07	-0.01	-0.02	-0.02

Chapter 5

Counterfactual analysis of the impact of high fixed prices

This chapter presents the results of a counterfactual experiment in which electricity prices follow a single pricing rule with all network costs recovered from fixed charges and remaining retail costs recovered using a variable charge (dollars per kWh). The price changes are shown to be welfare improving based on conventional money-metric measures of welfare changes. Distributional impacts are more equivocal though on average the price change leads to a reduction in inequality, and an improvement in social welfare, as measured by the Atkinson index.

5.1 Evaluation methods

The methods used here for evaluating impacts of alternative price structures follow Creedy and Mok (2018). First, money-metric measures of welfare changes are used to estimate the efficiency of price changes and aggregate welfare changes from a utilitarian perspective. This is the typical approach used in policy analysis of welfare effects of policy changes, predicated on the notion of Kaldor-Hicks efficiency where the only concern is whether policy changes lead to aggregate welfare gains because, hypothetically, transfers can be used to compensate those who are negatively impacted by policy changes (Adler and Posner, 2000).

Second, changes in inequality are analysed using the Atkinson index. This second step allows us to check the extent to which inequality worsens and thus address concerns that arise from the fact that policy or price changes are, in practice, not often accompanied by transfers. Furthermore, few people are indifferent to the distributional consequences of policy or price changes and most people are averse to transfers from low income households to high income households.

5.1.1 Compensating variation

Welfare changes are measured in terms of the compensating variation (CV) or estimated willingness to pay to avoid price changes. Analytically the calculation for the CV for a single household (h) in the QUAIDS model is:

$$\begin{aligned} cv_h &= e_h\left(p_h', u_{h0}\right) - e_h\left(p_h, u_{h0}\right) \\ &= \exp\left(\ln e_h\left(p_h', u_{h0}\right)\right) - \exp\left(e_h\left(p_h, u_{h0}\right)\right) \end{aligned} \tag{5.1}$$

where the first line is the standard expression for CV, expenditure evaluated at the new prices (p_h') and utility (u_{h0}) before the price change less expenditure given prices and utility before the price change, and the second line draws the connection to the model's empirical expenditure function in equation 2.6 and repeated below for ease of reference and with subscripts denoting households (h).

$$\ln e_h\left(p_h, u_h\right) = \ln m_h = \ln a(p_h) + b(p_h)\left[\frac{1}{\ln u_h} - \lambda(p_h)\right]^{-1}$$

Calculation of the CV requires an intermediate step of evaluating initial log-utility levels, in terms of expenditure, from the indirect utility function (equation 2.5):

$$\ln u_h = \left\{\left[\frac{\ln m_h - \ln a(p_h)}{b(p_h)}\right]^{-1} + \lambda(p_h)\right\}^{-1}$$

The standard expression for CV, in equation 5.1, is the same for both the QUAIDS and AIDS model, but the expenditure function and indirect utility functions to be evaluated are:

$$\ln e_h\left(p_h, u_h\right) = \ln a(p_h) + u_h \ln b(p_h) \tag{5.2}$$

$$\ln u_h = \frac{\ln m - \ln a(p_h)}{b(p_h)} \tag{5.3}$$

Two versions of the CV are considered here. One is as above with the household as the unit of account and without any adjustment for household size. The other is CV adjusted for household size using the equivalence scales discussed in section 4.1.2.

Creedy and Mok (2018) note that this approach to welfare evaluation is imperfect, ostensibly in deference to the fact that utility in consumer demand theory is a cardinal rather than ordinal concept.

Similarly, imperfections in model estimation and the specification of a functional form for indirect utility will invariably draw questions about whether the empirical estimates of money-metric utility are reasonable or not (Slesnick, 1998; Torres, Hanley, and Riera, 2011).

Nonetheless, inference about welfare effects is important given that most if not all policy decisions rely on judgements about welfare effects, whether explicit or not. The implicit claim here being that it is better that such analysis is carried out using a comparable and consistent evaluation method rather than ad-hoc reasoning. Further, the method laid out here is logically more coherent than other approaches, relying on the idea that even if we cannot measure utility itself we can measure how much money would be required to compensate people for price changes (Bockstael and McConnell, 2007).

Applied welfare analysis is most often based on rules-of-thumb or so-called sufficient statistics (Chetty, 2009), such as the widespread use of consumer surplus or Harberger triangles (Harberger, 1964). Such simplified methods are apt to ignore the effects of existing distortions affecting consumers, often assuming that the incremental policy under consideration is the only source of distortion. This is not as much of a problem here as all prices and substitution possibility are included in the welfare calculations (via price aggregators). Furthermore simplified methods are usually only reasonable where very small price changes are concerned (Kleven, 2020) and even then more complicated methods, such as the ones used here, substantially reduce the risk of biased estimates of welfare effects (Banks, Blundell, and Lewbel, 1996).

That said, it must be acknowledged that there are practical difficulties in inferring the effects of policy and price changes that are well-outside experience, that is non-marginal reforms, and these difficulties affect this analysis in so far as it reduces the reliability of the results.

5.1.2 Atkinson inequality measure

The Atkinson index (Atkinson, 1970) is a widely used metric for assessing inequality and impacts of policy changes on inequality. The index has also been frequently used in research in New Zealand analysing impacts of price and tax rate changes (Creedy, 2004; Creedy and Sleeman, 2005b, 2006; Creedy and Mok, 2018; Thomas, 2019).

The index, denoted A, is calculated via:

$$A = 1 - \frac{y_e}{\bar{y}} \tag{5.4}$$

$$y_e = \left(\frac{1}{N} \sum_{i}^{N} y_i^{1-\epsilon} \right)^{\frac{1}{1-\epsilon}} \tag{5.5}$$

$$\bar{y} = \frac{1}{N} \sum_{i}^{N} y_i \tag{5.6}$$

where y_i is a measure of income, y_e is a measure of equally distributed equivalent income, $\bar{y}$ is observed mean income, and ϵ is a parameter that represents social aversion to inequality. The equation for y_e posits a specific form of social welfare function.

The index can be interpreted as a function of (proportional to) societal willingness to pay to achieve a desired income distribution. It is also interpreted as the degree of tolerance for income loss in the process of making transfers (Creedy, 2016). The intuition for these interpretations is illustrated in Figure 5.1 for the case of two representative incomes y_1 and y_2.[1] In the diagram income is distributed at point a, with y_2 larger than y_1. An equal distribution would see incomes distributed at point b, where both y_1 and y_2 would be equal to mean income $\bar{y}$. The diagonal line passing between a and b represents an indifference curve for a utilitarian social welfare function, concerned only with the sum of income and not its distribution, such that a central planner would be indifferent between allocations a or b. The concave curve represents an alternative social welfare function with aversion to inequality where indifference between equal distribution of income at point c or unequal distribution of c represents indifference between two different average or total incomes y_e and $\bar{y}$, subject to the distribution of income.

[1]This figure has been adapted from a United Nations Food and Agriculture Organisation online resource available at `http://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/848138/`.

The rate of conversion of changes in the inequality index into income equivalents changes with the level of index (Creedy, 2016):

$$\frac{dy}{y} = \left(\frac{A}{(1-A)}\right)\frac{dA}{A} \tag{5.7}$$

where dy/y is the mean income change equivalent to the change in the Atkinson index.

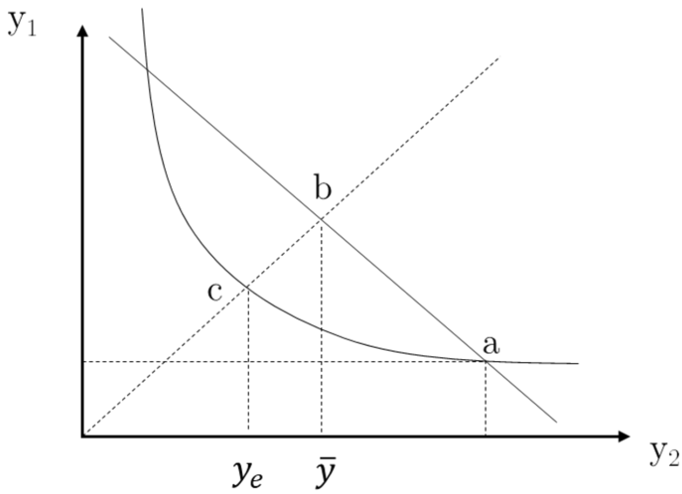

Figure 5.1: Intuition for the Atkinson index

The Atkinson index has the advantage, over other inequality measures, of being based on two simple and transparent assumptions: the functional form of the social welfare function and a single parameter of inequality aversion. The Atkinson index is not objective, however, for at least two reasons. First, measured inequality is a function of aversion to inequality with absolute amounts of inequality rising with the value of the aversion parameter. Second, changes in inequality are all relative to the starting point in terms of measured inequality (Creedy, 2016).

In this assessment the focus is on changes in inequality due to changes in electricity costs. Changes in inequality are estimated by measuring the Atkinson index based on population weighted disposable incomes before prices change and then measuring the Atkinson index based on population weighted disposable incomes after subtracting compensating variations, as discussed in section 5.1.1.[2]

[2]As discussed below, compensating variation values are presented here with reversed signs. However, the calculation of incomes after price changes involved subtracting compensating variations before sign reversal.

Table 5.1: Baseline Atkinson indices of equivalised real disposable income

	Inequality aversion ϵ			
Household	0.2	0.5	0.6	0.9
Single - no children	0.04	0.11	0.13	0.20
65+ single	0.03	0.07	0.08	0.12
Single - 1 child	0.03	0.07	0.08	0.13
Single - 2 children	0.03	0.08	0.09	0.14
Single - 3+ children	0.03	0.06	0.08	0.12
65+ couple	0.05	0.11	0.13	0.18
Couple - no children	0.03	0.09	0.10	0.15
Couple - 1 child	0.03	0.07	0.09	0.13
Couple - 2 children	0.03	0.07	0.08	0.12
Couple - 3+ children	0.03	0.09	0.10	0.15
3 adults - no children	0.02	0.06	0.07	0.11
3+ adults - 1+ children	0.03	0.07	0.08	0.12
4+ adults - no children	0.03	0.06	0.08	0.11
Total	0.04	0.10	0.12	0.17

Weighted average for 2007, 2010, 2013, 2016, 2019

Estimated changes in inequality used here include changes in inequality of equivalised income - using the equivalence scales discussed in section 4.1.2. Given that this adds an additional degree of subjectivity to our estimates, we analyse changes in inequality both with and without equivalisation for household size.

We consider a range of inequality parameters, consistent with those used in Creedy and Sleeman (2005a). However, within that we use a central estimate for inequality aversion of 0.60 based on an estimate of observed inequality aversion for Australia (of 0.62) from a cross-country study by Lambert, Millimet, and Slottje (2003).

Table 5.1 provides a summary of inequality measures for the baseline model, with variations by inequality aversion parameter and inequality measures for household types as well as across all households. In this table the income measure is equivalised disposable income and the indices are population weighted averages over indices for individual HES survey years. Complementary tables can be found in appendix D, showing indices by survey year (Table D.1) and indices for unequivalised disposable income (Table D.2).

5.2 Tariff restructuring scenario

To estimate the effects of higher fixed prices in electricity tariffs we consider a scenario where all network (distribution and transmission) costs recovered from residential consumers are recovered in fixed equal annual amounts per household, with the annual fixed charges varying by network area.

Modelled counterfactual prices are summarised in Tables 5.2 and Table 5.3. The Tables show nominal national average prices by household type and by income quintile over the period 2007 to 2019. Smaller households would face price increases, on average, while larger households face price declines. Lower income households would also face price increases.

Price variation, by household type, in the baseline reflects a combination of the effects of low fixed charge regulations, which see smaller households paying lower fixed charges and higher variable charges, and differences in household demographics across network areas where energy and network costs differ. Similarly, under the counterfactual scenario fixed charges vary because of differences in household demographics across network areas. Variable prices ($/kWh prices) vary much less than fixed charges because variance in network costs is larger, across network areas, than variance in average energy and other costs.[3]

The advantage of this simple price change scenario is that there is no need for complicated optimisation of two-part tariffs to ensure that network owners fully recover their costs. The calculation of counterfactual tariffs simply requires calculating network costs recovered, per connection, from within a network area and determining the level of variable (per kWh) charges required to cover other non-network costs on an average cost basis.

[3]Other costs include costs of metering, billing, and account management including the cost of managing wholesale energy price risk. There is regional variation in these costs, including because of differences in competition and locational pricing of energy to reflect transport congestion costs and losses. However network costs typically vary more spatially than do energy costs.

Table 5.2: Prices used in counterfactual pricing scenario, by household

	Baseline prices:			Counterfactual prices:			
	Fixed	Variable	Average	Fixed	Variable	Average	Price change
Household type:	$ per year	$/kWh	$/kWh	$ per year	$/kWh	$/kWh	Percent
Single - no children	150	0.24	0.266	808	0.150	0.307	15.4
65+ single	155	0.24	0.269	800	0.152	0.301	12.0
Single - 1 child	185	0.23	0.261	799	0.149	0.275	5.5
Single - 2 children	213	0.23	0.261	814	0.151	0.263	1.0
Single - 3+ children	240	0.23	0.256	807	0.150	0.247	-3.3
65+ couple	217	0.24	0.265	813	0.154	0.263	-0.8
Couple - no children	213	0.23	0.260	810	0.151	0.262	1.1
Couple - 1 child	248	0.23	0.255	810	0.150	0.248	-3.0
Couple - 2 children	269	0.22	0.249	818	0.149	0.233	-6.6
Couple - 3+ children	294	0.22	0.247	815	0.150	0.225	-8.9
3 adults - no children	261	0.23	0.253	822	0.151	0.237	-6.6
3+ adults - 1+ children	301	0.22	0.246	836	0.150	0.219	-11.1
4+ adults - no children	273	0.22	0.245	818	0.150	0.215	-12.6

Population weighted average over 2007, 2010, 2013, 2016, and 2019.

Table 5.3: Prices used in counterfactual pricing scenario, by income quintile

	Baseline prices:			Counterfactual prices:			
	Fixed	Variable	Average	Fixed	Variable	Average	Price change
Income quintile:	$ per year	$/kWh	$/kWh	$ per year	$/kWh	$/kWh	Percent
1	216	0.234	0.263	820	0.152	0.269	2.4
2	220	0.232	0.260	811	0.152	0.261	0.6
3	224	0.229	0.257	810	0.151	0.257	-0.1
4	224	0.228	0.255	809	0.150	0.254	-0.6
5	246	0.225	0.253	815	0.149	0.248	-1.9

Population weighted average over 2007, 2010, 2013, 2016, and 2019.

A single pricing rule for all households and for all network is a little crude. In practice there may be advantages to some network owners from more nuanced pricing methodologies such as using demand or time-of-use charges for rationing access to limited capacity during peak periods (that is, for signalling congestion costs). It may also be that there are people who would be prompted to disconnect from networks if fixed charges are too high. While it is unlikely that this would be a widespread phenomenon, it would be efficient for network owners or retailers to vary fixed charges, where practically feasible, to avoid causing disconnections that would cause an increase in the fixed charges of remaining connected customers.

5.3 Welfare effects of high fixed charges

5.3.1 Aggregate welfare effects and efficiency

A shift to higher fixed charges results in an increase aggregate household welfare, as measured by estimated compensating variation unadjusted for distributional effects. An increase in welfare is found for both the QUAIDS model of household demand and for the AIDS model of household demand.

Tables 5.4 and 5.5 summarise compensating variations by household and disposable income quintile. The size of the welfare change shown here is an aggregate over each of the five HES survey years used in the demand systems: 2007, 2010, 2013, 2016, and 2019. Changes in compensating variation by survey year are summarised in Tables D.3 and D.4 in appendix D.

In all presentations of welfare results the sign of the compensating variation has been reversed for ease of interpretation; in tables of results positive compensating variation indicates a welfare gain. Strictly speaking, without sign reversal, a negative compensating variation indicates that a household would be willing to pay for a change in the structure of pricing while a positive compensating variation indicates that a household would have to be paid to be indifferent between the status quo and the counterfactual pricing regime.

To put the welfare gains into context, the compensating variation estimated with the QUAIDS model averages 5.0 percent of total residential expenditure on electricity, across each of the survey years, and the compensating variation estimated with the AIDS model averages 2.2 percent of total residential expenditure on electricity.

There are two ways to interpret the compensating variations in Tables 5.4 and 5.5 in light of the fact that they represent a sum over five non-adjacent years. One is to view each year's result as the effect of a price change in the third year after the price change. This interpretation is the same as the interpretation of own-price elasticities of demand as changes in demand over at least three years in response to a persistent one-off change in prices. That is, it takes at least three years for the price change to reach full effect. On this interpretation, the impact on consumer welfare over the fifteen year period spanned by the model (2007-2019) is a multiple of the modelled effects and the multiple is less than three. On this interpretation, and assuming an equal annual increases in compensating variation over three years, the total value of the compensating variation over the fifteen years is 1.4 billion for the estimates from the QUAIDS model and 600 million for the estimates from the AIDS model.

The alternative view, is that the the compensating variations reflect impacts on welfare if prices had always included higher fixed charges, relative to the status quo. On that view, the change in compensating variation, over the fifteen year period modelled, is three times the modelled compensating variation. That is, 2.3 billion for the estimates from the QUAIDS model and 1.0 billion for the estimates from the AIDS model.

This latter perspective is questionable in the sense that once-and-for-all and large changes in the structure of pricing are likely to have structural effects, in terms of industry cost structures and consumer investment, that are not captured in the demand model. This is an issue related to the Lucas critique of macroeconomic models, which questions inferences about effects of policy changes made using models calibrated to data obtained under an alternative policy regime. While the models estimated here are structural and behavioural, so less subject to the Lucas critique, they are not general equilibrium models and do not capture all relevant effects. They need to be interpreted as local models, the validity of which can be questioned in light of the large price changes to price structures being modelled.

Results in Tables 5.4 and 5.5 show that low income households and small households are worse off from a shift to high fixed charges to cover all network costs.[4] However,

[4]Tables of mean compensating variations per household, corresponding to these aggregate results, can be found in Tables D.5 and D.6 in appendix D

Table 5.4: Aggregate compensating variation, QUAIDS model, 2017 dollar millions

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-6.1	-2.2	-1.2	3.3	13.3	7.1
65+ single	-6.6	-4.8	-3.7	-4.8	3.1	-16.8
Single - 1 child	-0.2	-0.5	0.1	0.5	3.0	3.0
Single - 2 children	0.1	0.0	0.9	0.6	2.8	4.4
Single - 3+ children	0.1	-0.3	0.1	2.8	0.6	3.3
65+ couple	-3.0	-1.0	1.6	8.5	26.3	32.5
Couple - no children	6.9	22.0	35.8	44.1	75.8	184.6
Couple - 1 child	5.8	12.0	9.5	15.6	34.9	77.7
Couple - 2 children	11.1	25.1	26.1	28.2	42.6	133.1
Couple - 3+ children	6.7	9.4	4.9	13.0	20.4	54.4
3 adults - no children	10.6	9.3	13.6	34.9	35.9	104.3
3+ adults - 1+ children	10.7	18.7	21.4	19.6	49.9	120.3
4+ adults - no children	7.2	16.2	21.4	6.8	13.8	65.3
Total	43	104	131	173	323	773.2

Population weighted sum 2007, 2010, 2013, 2016, 2019.
Income quintile ordered from lowest to highest.
Sign of CV reversed. Positive values represent welfare gains.

the results from the QUAIDS model suggests that sole occupant households aged 65 or older are the only household type that, in aggregate, is worse off. This reflects two things. One is heterogeneity in electricity consumption and price effects within each household type by income quintile (that is, within each cell of Tables 5.4 and 5.5), such that the vast majority of smaller households consume below average amounts of electricity and would face price increases, a minority consume relatively large amounts of electricity and would enjoy price reductions.

The second and main reason that the QUAIDS model shows sole occupant households aged 65 or older to be the only household type that, in aggregate, is worse off is non-linear impacts on compensating variation such that the gains of a subset of households within each combination of household type and income quintile is sufficiently large, in aggregate, as to offset more numerous small losses by other households within

Table 5.5: Aggregate compensating variation, AIDS model, 2017 dollar millions

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-8.6	-4.9	-4.9	-4.1	4.0	-18.5
65+ single	-7.8	-5.2	-5.0	-7.2	-1.1	-26.3
Single - 1 child	-3.5	-1.1	-2.1	-1.1	0.8	-7.0
Single - 2 children	-0.5	-0.3	-0.6	-0.8	1.9	-0.3
Single - 3+ children	-0.4	-0.9	-0.2	1.0	0.0	-0.6
65+ couple	-7.8	-5.8	-3.9	0.3	13.7	-3.4
Couple - no children	-7.3	1.6	10.3	22.3	50.7	77.7
Couple - 1 child	-1.2	3.3	3.8	6.7	24.7	37.2
Couple - 2 children	3.3	11.3	12.8	16.8	36.7	80.9
Couple - 3+ children	0.1	3.0	2.5	6.9	14.5	27.1
3 adults - no children	1.2	0.2	6.4	25.6	25.6	59.0
3+ adults - 1+ children	2.3	9.9	11.1	11.0	44.6	78.8
4+ adults - no children	2.1	9.4	14.8	3.7	8.7	38.6
Total	-28	20	45	81	225	343.2

Population weighted sum 2007, 2010, 2013, 2016, 2019.
Income quintile ordered from lowest to highest.
Sign of CV reversed. Positive values represent welfare gains.

the group.

Non-linear impacts on compensating variation, in the QUAIDS model, can be seen in a comparison of aggregate compensating variation in Table 5.4 and mean household compensating variation as a percentage of disposable income in Table 5.6. While the aggregate compensating variation is shown to be positive for sole occupant households under 65 years of age the mean compensating variation, as a percentage of total income, is negative. Similarly, the majority of single parent households with one child and couple households aged 65 years or older experience a negative welfare effect, even though in aggregate these types of households are shown to benefit from the price changes.

Differences between aggregate effects and mean effects as a percentage of disposable income also reflect that lower income households within each income quintile are generally worse than the higher income households, other things being equal.

Table 5.6: Mean compensating variation as a percentage of disposable income, QUAIDS model

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-0.47%	-0.17%	-0.06%	0.01%	0.12%	-0.12%
65+ single	-0.30%	-0.27%	-0.24%	-0.26%	-0.03%	-0.22%
Single - 1 child	-0.08%	-0.05%	-0.02%	0.00%	0.14%	-0.01%
Single - 2 children	-0.04%	0.00%	0.03%	0.05%	0.14%	0.03%
Single - 3+ children	-0.01%	-0.12%	-0.01%	0.31%	0.08%	0.05%
65+ couple	-0.20%	-0.09%	-0.02%	0.06%	0.23%	-0.01%
Couple - no children	-0.03%	0.12%	0.17%	0.18%	0.29%	0.14%
Couple - 1 child	0.02%	0.15%	0.11%	0.17%	0.30%	0.15%
Couple - 2 children	0.09%	0.28%	0.23%	0.28%	0.27%	0.23%
Couple - 3+ children	0.09%	0.19%	0.08%	0.22%	0.34%	0.18%
3 adults - no children	0.13%	0.12%	0.14%	0.32%	0.32%	0.20%
3+ adults - 1+ children	0.13%	0.23%	0.23%	0.23%	0.38%	0.24%
4+ adults - no children	0.19%	0.31%	0.37%	0.11%	0.25%	0.24%
Total	-0.07%	0.06%	0.08%	0.12%	0.23%	0.08%

Population weighted means 2007, 2010, 2013, 2016, 2019.
Income quintile ordered from lowest to highest.
Sign of CV reversed. Positive values represent welfare gains.

In contrast to the QUAIDS model, the AIDS model shows mean compensating variations, as a percentage of disposable income in Table 5.6 that in most cases have the same sign as the aggregate compensating variations in Table 5.5. The only exceptions are for larger households with two or more adults and four or more occupants and in the lowest quintile of disposable income where mean compensating variations are negative but aggregate compensating variations are positive.

The differences between the AIDS and QUAIDS results indicates that the welfare analysis is highly sensitive to the use of the quadratic model with nonlinear welfare effects.

Table 5.7: Mean compensating variation as a percentage of disposable income, AIDS model

Household	Disposable income quintile: 1	2	3	4	5	Total
Single - no children	-0.43%	-0.19%	-0.13%	-0.09%	0.00%	-0.17%
65+ single	-0.32%	-0.25%	-0.24%	-0.29%	-0.08%	-0.24%
Single - 1 child	-0.34%	-0.10%	-0.16%	-0.10%	0.03%	-0.14%
Single - 2 children	-0.11%	-0.04%	-0.11%	-0.11%	0.07%	-0.07%
Single - 3+ children	-0.13%	-0.25%	-0.08%	0.11%	-0.02%	-0.08%
65+ couple	-0.28%	-0.18%	-0.12%	-0.05%	0.09%	-0.11%
Couple - no children	-0.13%	-0.02%	0.02%	0.07%	0.17%	0.02%
Couple - 1 child	-0.10%	0.03%	0.03%	0.05%	0.19%	0.04%
Couple - 2 children	-0.01%	0.11%	0.09%	0.15%	0.23%	0.11%
Couple - 3+ children	-0.10%	0.02%	0.03%	0.10%	0.21%	0.05%
3 adults - no children	-0.02%	-0.04%	0.04%	0.21%	0.20%	0.08%
3+ adults - 1+ children	-0.02%	0.09%	0.08%	0.11%	0.30%	0.11%
4+ adults - no children	0.02%	0.17%	0.22%	0.05%	0.16%	0.12%
Total	-0.16%	-0.05%	-0.02%	0.02%	0.13%	-0.02%

Population weighted means 2007, 2010, 2013, 2016, 2019.
Income quintile ordered from lowest to highest.
Sign of CV reversed. Positive values represent welfare gains.

In principle, the non-linearity of the QUAIDS model is a strength, in light of the fact that it is unwise to reason on the average if phenomena are non-linear and given that observed distributions of both electricity consumption and household expenditure have long right tails.

In practice, however, it seems wise to treat the non-linear results from the QUAIDS model with some caution. The consequence of model error is potentially large, given non-linearities. Furthermore, the effects on some combinations of household type and income are inferred from limited numbers of observations. That is, the QUAIDS model results are heavily influenced by a small number of observations.

The efficiency gains from the change in price structures are smaller when based on

Table 5.8: Aggregate equivalised compensating variation, QUAIDS model, 2017 dollar millions

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-6.1	-2.2	-1.2	3.3	13.3	7.1
65+ single	-6.6	-4.8	-3.7	-4.8	3.1	-16.8
Single - 1 child	-0.1	-0.4	0.1	0.4	2.5	2.5
Single - 2 children	0.1	0.0	0.7	0.4	2.0	3.2
Single - 3+ children	0.1	-0.1	0.0	1.8	0.4	2.1
65+ couple	-2.3	-0.7	1.2	6.4	19.9	24.6
Couple - no children	5.3	16.7	27.1	33.4	57.5	139.9
Couple - 1 child	3.9	8.2	6.5	10.6	23.9	53.1
Couple - 2 children	7.0	15.8	16.4	17.8	26.8	83.8
Couple - 3+ children	3.9	5.4	2.9	7.5	11.8	31.4
3 adults - no children	6.8	6.0	8.8	22.5	23.1	67.2
3+ adults - 1+ children	6.3	10.6	11.8	11.0	26.6	66.3
4+ adults - no children	4.1	8.8	12.2	3.9	7.8	36.7
Total	22	63	83	114	219	501.1

Population weighted sum 2007, 2010, 2013, 2016, 2019.
Income quintile ordered from lowest to highest.
Sign of CV reversed. Positive values represent welfare gains.

equivalised compensating variation as summarised in Tables 5.8 and 5.9.

5.3.2 Impacts of high fixed charges on inequality

A shift to high fixed charges is estimated to reduce income inequality, as measured by the Atkinson index. This general finding is not sensitive to the choice of inequality aversion parameter (ϵ) or to QUAIDS or AIDS model specification.

Percentage changes in the Atkinson index are summarised in Tables 5.10 and 5.11. The effect on income inequality is predictably small given the relatively small share of electricity in household expenditure. The total changes in inequality, using the

Table 5.9: Aggregate equivalised compensating variation, AIDS model, 2017 dollar millions

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-8.6	-4.9	-4.9	-4.1	4.0	-18.5
65+ single	-7.8	-5.2	-5.0	-7.2	-1.1	-26.3
Single - 1 child	-2.9	-1.0	-1.7	-0.9	0.6	-5.8
Single - 2 children	-0.4	-0.2	-0.4	-0.6	1.4	-0.2
Single - 3+ children	-0.3	-0.6	-0.2	0.6	0.0	-0.4
65+ couple	-5.9	-4.4	-2.9	0.2	10.4	-2.6
Couple - no children	-5.5	1.2	7.8	16.9	38.4	58.9
Couple - 1 child	-0.8	2.3	2.6	4.6	16.9	25.4
Couple - 2 children	2.1	7.1	8.1	10.6	23.1	50.9
Couple - 3+ children	0.1	1.7	1.4	4.0	8.4	15.7
3 adults - no children	0.8	0.1	4.1	16.5	16.5	38.0
3+ adults - 1+ children	1.5	5.6	6.1	6.2	23.6	43.0
4+ adults - no children	1.1	5.1	8.4	2.1	5.0	21.7
Total	-27	7	23	49	147	199.8

Population weighted sum 2007, 2010, 2013, 2016, 2019.
Income quintile ordered from lowest to highest.
Sign of CV reversed. Positive values represent welfare gains.

QUAIDS model, range from -0.17 percent where $\epsilon = 0.5$ to -0.34 percent where $\epsilon = 0.2$. In terms of absolute changes (in number of index units), the changes in inequality are smallest at $\epsilon = 0.2$ and largest at $\epsilon = 0.9$.

Higher rates of inequality aversion give higher weight (greater weight in social welfare) to low income households in the construction of the Atkinson index. Thus the fact that the impact on inequality gets larger, in absolute terms, as the rate of inequality aversion rises indicates that the source of the inequality reduction is, on balance, positive impacts on lower income households.

Inequality does not decline in every year, rather it is shown to increase in 2007 and 2016. That being so, these findings are not generalisable without qualification that

Table 5.10: Percentage change in Atkinson index of equivalised income, QUAIDS model

	Inequality aversion ϵ			
Household	0.2	0.5	0.6	0.9
Single - no children	0.08	0.07	0.07	0.07
65+ single	-5.34	-3.09	-3.06	-3.94
Single - 1 child	0.24	0.23	0.23	0.20
Single - 2 children	-0.06	-0.72	-1.12	-3.38
Single - 3+ children	0.18	0.19	0.20	0.22
65+ couple	-0.36	-0.31	-0.28	-0.14
Couple - no children	0.02	0.01	0.00	-0.04
Couple - 1 child	-0.38	-0.40	-0.41	-0.41
Couple - 2 children	-0.35	-0.31	-0.29	-0.20
Couple - 3+ children	-0.16	-0.23	-0.28	-0.65
3 adults - no children	-0.22	-0.22	-0.21	-0.19
3+ adults - 1+ children	0.09	0.13	0.14	0.17
4+ adults - no children	0.18	0.12	0.10	0.06
Total	-0.34	-0.17	-0.17	-0.25

Weighted average for 2007, 2010, 2013, 2016, 2019

they are data or context-specific. Annual changes in inequality can be found in Tables D.7 and D.7 in appendix D.

The findings of reduced inequality on average do, however, provide evidence against presumptions of negative distributional consequences of higher fixed charges. Furthermore, even if there are instances of negative effects that require correction there are sufficiently large aggregate welfare or efficiency gains from a shift to higher fixed charges that targeted transfers could be used to compensate negatively effected households without undermining overall efficiency improvements and welfare gains.

Interestingly, the shift to higher fixed charges is estimated to cause a decline in within-group inequality for households of people aged 65 or older whether living alone or in couples. This reflects relatively large increases in average electricity prices for a subset of higher income households who consume comparatively little electricity.

Table 5.11: Percentage change in Atkinson index of equivalised income, AIDS model

	Inequality aversion ϵ:			
Household	0.2	0.5	0.6	0.9
Single - no children	0.17	0.19	0.21	0.31
65+ single	-5.31	-3.00	-2.92	-3.51
Single - 1 child	0.67	0.72	0.74	0.80
Single - 2 children	0.41	0.22	0.09	-0.76
Single - 3+ children	0.36	0.41	0.44	0.54
65+ couple	-0.30	-0.26	-0.24	-0.09
Couple - no children	0.12	0.10	0.10	0.05
Couple - 1 child	-0.28	-0.31	-0.32	-0.35
Couple - 2 children	-0.20	-0.17	-0.15	-0.10
Couple - 3+ children	0.10	0.12	0.14	0.25
3 adults - no children	-0.10	-0.09	-0.09	-0.08
3+ adults - 1+ children	0.24	0.27	0.28	0.31
4+ adults - no children	0.33	0.28	0.26	0.22
Total	-0.24	-0.06	-0.04	-0.06

Weighted average for 2007, 2010, 2013, 2016, 2019

This in turn reflects the comparatively high income and comparatively low electricity consumption of households that remain connected to the labour force. Furthermore, although our data does not provide evidence for it, this may be due to wealthier households being more likely to have greater access to a range of energy sources including reticulated gas or self-production with solar photovoltaics.

Measured changes in inequality are sensitive to equivalisation. Inequality falls by less if income is measured by disposable income without equivalisation (see Table D.9 in appendix D). However the general finding of, on balance, a reduction in inequality does not change.

Converting the changes in the Atkinson indices into changes in social welfare, using the relationship in equation 5.7, finds an average gain in social welfare across each of the models and for equivalised and unequivalised income. This is summarised in Table 5.12. The social welfare changes range from an average annual improvement valued at

1 million dollars through to an average annual improvement of 24 million dollars.

The social welfare changes, based on the social welfare function underpinning the Atkinson index, are apt to understate potential welfare gains because of the fact that the aggregate welfare gains permit funding of targeted assistance, which could, in principle, further reduce inequality.

Table 5.12: Changes in social welfare based on changes in Atkinson index social welfare function

	Year:					
	2007	2010	2013	2016	2019	Average
National household disposable income, 2017 dollar millions:						
Unequivalised income	114,846	125,540	132,744	146,718	170,666	
Equivalised income	75,752	81,982	83,022	94,601	111,425	
QUAIDS model, equivalised income, $\epsilon = 0.6$:						
A_0	0.1136	0.1110	0.1170	0.1120	0.1287	
A_1	0.1137	0.1106	0.1166	0.1123	0.1281	
Social welfare change	-1.9	33.2	36.1	-36.6	72.4	20.6
QUAIDS model, unequivalised income, $\epsilon = 0.6$:						
A_0	0.1354	0.1320	0.1377	0.1302	0.1539	
A_1	0.1355	0.1317	0.1375	0.1306	0.1533	
Social welfare change	-7.6	55.1	36.9	-68.6	105.9	24.3
AIDS model, equivalised income, $\epsilon = 0.6$:						
A_0	0.1136	0.1110	0.1170	0.1120	0.1287	
A_1	0.1138	0.1108	0.1167	0.1124	0.1284	
Social welfare change	-14.9	19.6	27.6	-42.6	38.0	5.5
AIDS model, unequivalised income, $\epsilon = 0.6$:						
A_0	0.1354	0.1320	0.1377	0.1302	0.1539	
A_1	0.1356	0.1318	0.1376	0.1306	0.1536	
Social welfare change	-27.7	35.1	23.0	-76.8	51.8	1.1

Social welfare changes in millions of 2017 dollars

Chapter 6

Conclusions

This research finds evidence against the hypothesis that high fixed charges in residential electricity tariffs would reduce social welfare or increase inequality. Rather, high kWh prices are found to reduce consumer welfare and exacerbate inequality.

This central finding is empirical evidence for a basic tenet of economics: that efficient prices should reflect marginal costs. Recovering network costs through high kWh prices, much higher than marginal costs, is inefficient because it causes people to economise on electricity use for no good reason. It acts like a tax on electricity consumption.

Efficiently recovering non-marginal costs is a perennial problem in economics, in politics and for pricing practitioners. There is no single best way for recovering non-marginal costs in network industries with significant economies of scale. Empirical analysis is needed to help identify the better of numerous methods for recovering network owners' sunk costs.

The main empirical contribution of this research is to analyse the balance of effects of pricing reforms across different types of households. In this hypothetical pricing reform high kWh charges are reduced and fixed charges are increased significantly, such that all network (distribution and transmission) costs recovered from residential consumers are recovered from fixed charges.

Aggregate efficiency gains from this tariff reform range from 2.2 percent to 5.0 percent of total residential expenditure. These are non-trivial gains in light of the fact that residential electricity expenditure exceeds 3 billion dollars annually.

Further, inequality is estimated to reduce with a pricing rule that includes high fixed charges. This effect is more equivocal than the finding of aggregate efficiency gains but, on balance, it refutes presumptions that high kWh charges are progressive because higher income households consume more electricity than lower income households. This result follows somewhat naturally from the observation household composition - age, number of adults and number of children - has a larger effect on electricity expenditure than household income.

Empirical results such as these will invariably raise questions about the methods of analysis and whether alternative methods would contradict these results. There are no simple answers to these questions, but this research does provide insights into the sensitivity of model results to model specification. This is something that is often overlooked in empirical analysis using demand systems.

First, the QUAIDS model produces substantially larger estimates of price elasticities of demand and welfare effects than the AIDS model. This could be read in two different ways. One is that AIDS models are not a good approximation to QUIADS models - that the inclusion of a quadratic income effect is empirically consequential. The other is that the QUAIDS model is more sensitive to variations in the model data, apt to be influenced by a small number of observations, and more sensitive to sub-optimal sample sizes or errors in the data. Either way, it is shown that choice of model specification is empirically important.

Second, model specification choices, such as restrictions and choice of demographic variables, have a material effect on the empirical implications and economic interpretations of the QUAIDS model results. A case in point is the long-run uncompensated own price elasticities for electricity range which range from -1.2 to -2.7 in the models tested here. This result is important because most studies do not report these sorts of results and researchers have no guide, *a priori*, about whether or not their model specification choices are of much empirical consequence and thus how much effort should be expended in identifying a sound model specification. And readers of research have no way to know whether the single model specification presented to them is very sensitive to these sorts of choices. The results of that sensitivity tests suggest that researchers should conduct and report more sensitivity analyses and readers should be sceptical of models that do not report such tests.

Further research could improve understanding about electricity pricing and demand modelling by building on the framework and methods used here. Natural extensions or additions follow from the simplifications in this research. For example, the model used here contained a simplified treatment of differences in demographics and preferences amongst households. Application of the price scaling method of Ray (1983), where equivalence scales for household sizes are endogenous and vary with relative prices, would be a substantial improvement. The estimated equivalence scales would be fully consistent with the underlying theoretical model. Importantly it would provide for a more nuanced understanding of economies of costs of living, household economies of scale, and costs of children.

Accurate information on costs of living is practically very important. It is of central importance for research into income inequality and thus influences income support and social assistance policies. Estimates of costs of living are also used by Department of Inland Revenue for setting tax rules and calculating child support obligations. In the private sector, banks use estimates of costs of living to set lending criteria.

As discussed in the introductory chapter, analysis of natural experiments or perhaps quasi-experimental analysis would be a valuable methodological extension or alternative to deepen understanding of household electricity demand. Consumer behaviour can be shown to deviate from theoretically optimal behaviour. While this does not invalidate consumer-theoretic analysis altogether, less theoretically restrictive analysis could provide different insights and insights less encumbered by theory. Experimental or quasi-experimental analysis would thus complement the methods used in this research.

The electricity sector is replete with natural experiments from changes to pricing structures and to policies that vary across across will-defined boundaries. Although connecting data on electricity consumption and prices to household characteristics is challenging.

Replication of the analysis of Beatty *et al.* (2014) would be valuable; exploiting the natural experiment of the introduction of a winter energy payment. This sort of behavioural and quasi-experimental analysis has not been carried out in New Zealand before. Understanding how people on low incomes respond to the winter energy payments would be very valuable such as for calibrating targeted transfer payments, if necessary, in the event that, for example, steps are taken to repeal the low fixed charge regulations. It is practically very important to find ways to improve the acceptability of ostensibly efficient policy changes. This may include targeted transfers.

A central premise of this research is that the welfare effects of prices for recovery of sunk costs has been insufficiently interrogated in New Zealand. Thus this research considers only high fixed charges and two-part tariffs. These practical simplifications miss two important elements of electricity pricing: consumer choice over prices and efficient peak load pricing. A more complete analysis of the efficiency of electricity pricing would address these things by analysing menus of prices and multi-part tariffs.

Menus of tariffs are more efficient than single pricing rules because they allow people to choose the kinds of services and pricing options that suit them. Furthermore, consumer choice in the context of multiple non-linear prices is of central importance to policy because it is a major source of political tension. Multi-part tariffs and menus of tariffs are methods for price discrimination and while price discrimination can be welfare improving (Wilson, 1993) it is very often a source of concern in terms of distributional consequences.

It is important that prices signal incremental costs of demand, where these costs are material, and thus due consideration must be given to including marginal costs subject to analysis of the impacts of those prices and taking account of imperfections in consumer behaviour. It is possible that incremental costs will become increasingly important for electricity pricing. Charging of electric vehicles is a case in point. It is possible that electric vehicle charging could place substantial and unnecessary stress on distribution networks. Pricing that incentivises charging of vehicles outside of distribution network peaks could help to manage this risk.

Thus, in summary, there are many nuances to electricity pricing that are not considered here. This is but one contribution to improving one aspect of pricing. Nonetheless, the hope is that these results are of practical use even if only as a challenge to preconceptions about what makes for efficient and equitable electricity pricing.

Appendix A

Classifications

Table A.1: Product categories

Expenditure groups:	Components: NZHEC code	Description
Accommodation	04.1.01	Actual rentals for housing
	04.2.01	Purchase of housing
	04.3.01	Property maintenance materials
	04.3.02	Property maintenance services
	04.4.01	Water supply
	04.4.02	Refuse disposal and recycling
	04.4.03	Local authority rates and payments
	04.4.04	Other property related services
Air transport	07.3.03	Domestic air transport
	07.3.04	International air transport
Alcohol	02.1.01	Beer
	02.1.02	Wine
	02.1.03	Spirits and liqueurs
	02.2.00	Cigarettes and tobacco
Clothing	03.1.02	Men's clothing
	03.1.03	Women's clothing
	03.1.04	Children's and infants' clothing

Continued on next page

Product groupings, continued from previous page

Expenditure groups:	NZHEC code	Description
	03.1.05	Clothing accessories
	03.1.06	Knitting and sewing supplies
	03.1.07	Clothing services
	03.2.02	Men's footwear
	03.2.03	Women's footwear
	03.2.04	Children's and infants' footwear
Communication	08.1.00	Postal services
	08.2.00	Telecommunication equipment
	08.3.00	Telecommunication services
Contents	05.1.01	Furniture and furnishings
	05.1.02	Carpets and other floor coverings
	05.2.00	Household textiles
	05.3.01	Major household appliances
	05.3.02	Small electrical household appliances
	05.3.03	Repair and hire of household appliances
	05.4.00	Glassware, tableware and household utensils
	05.5.01	Major tools and equipment for the house and garden
	05.5.02	Small tools and accessories for the house and garden
	05.6.01	Cleaning products and other household supplies
	05.6.02	Other household services
Education	10.1.00	Early childhood education
	10.2.00	Primary and secondary education
	10.3.00	Tertiary and other post school education
	10.4.00	Other educational fees
Electricity	04.5.01	Electricity
Other energy	04.5.02	Gas

Continued on next page

Product groupings, continued from previous page

Expenditure groups:	NZHEC code	Description
	04.5.03	Solid fuels
Food	01.1.01	Fruit
	01.1.02	Vegetables
	01.2.01	Meat and poultry
	01.2.02	Fish and other seafood
	01.3.01	Bread and cereals
	01.3.02	Milk, cheese and eggs
	01.3.03	Oils and fats
	01.3.04	Food additives and condiments
	01.3.05	Confectionery, nuts and snacks
	01.3.06	Other grocery food
	01.4.01	Coffee, tea and other hot drinks
	01.4.02	Soft drinks, waters and juices
Health	06.1.01	Pharmaceutical products
	06.1.02	Other medical products
	06.1.03	Therapeutic appliances and equipment
	06.2.01	Medical services
	06.2.02	Dental services
	06.2.03	Paramedical services
	06.3.00	Hospital services
Insurance	11.4.01	Life insurance
	11.4.02	Dwelling insurance
	11.4.03	Contents insurance
	11.4.04	Health insurance
	11.4.05	Vehicle insurance
Other	11.1.01	Hairdressing and personal grooming services
	11.1.02	Electrical appliances for personal care
	11.1.03	Other appliances, articles and products for personal care
	11.3.01	Jewellery and watches

Continued on next page

Product groupings, continued from previous page

Expenditure groups:	NZHEC code	Description
	11.3.02	Other personal effects
	11.6.01	Vocational services
	11.6.02	Professional services
	11.6.03	Real estate services
	11.6.04	Other miscellaneous services not elsewhere classified
Recreation and culture	09.1.01	Audio-visual equipment
	09.1.02	Computing equipment
	09.1.03	Recording media
	09.2.00	Major recreational and cultural equipment
	09.3.01	Games, toys and hobbies
	09.3.02	Equipment for sport, camping and outdoor recreation
	09.3.03	Plants, flowers and gardening supplies
	09.3.04	Pets and pet-related products
	09.4.01	Recreational and sporting services
	09.4.02	Cultural services
	09.4.03	Veterinary services
	09.5.01	Books
	09.5.02	Newspapers and magazines
	09.5.04	Stationery and drawing materials
	09.6.00	Accommodation services
Takeaways	01.5.01	Restaurant meals
	01.5.02	Ready-to-eat food
Transport	07.2.01	Vehicle parts and accessories
	07.2.02	Petrol
	07.2.03	Other vehicle fuels and lubricants
	07.2.04	Vehicle servicing and repairs
	07.2.05	Other private transport services
	07.3.01	Rail passenger transport

Continued on next page

Product groupings, continued from previous page

Expenditure groups:	NZHEC code	Description
	07.3.02	Road passenger transport
	07.3.05	Sea passenger transport
Vehicles	07.1.01	Purchase of new motor cars
	07.1.02	Purchase of second-hand motor cars
	07.1.03	Purchase of motorcycles
	07.1.04	Purchase of bicycles

NZHEC is NZ Household expenditure classification.

Table A.2: Geographic concordance for QSDEP data

QSDEP area	Territorial local authority
Ashburton	Ashburton District
Auckland Central	Auckland
Auckland North Shore	Auckland
Balclutha	Clutha District
Blenhiem	Marlborough District
Cambridge	Waipa District
Christchurch	Christchurch City
Christchurch	Selwyn District
Cromwell	Central Otago District
Dannevirke	Tararua District
Dunedin	Dunedin City
Gisborne	Gisborne District
Gisborne	Wairoa District
Greymouth	Grey District
Greymouth	Westland District
Hamilton	Hamilton City
Hawera	South Taranaki District
Invercargill	Invercargill City
Kaiapoi	Waimakariri District
Kerikeri	Far North District

QSDEP concordance, continued on next page

QSDEP concordance, continued from previous page

QSDEP area	Territorial local authority
Masterton	Carterton District
Masterton	Masterton District
Masterton	South Wairarapa District
Napier	Hastings District
Napier	Napier City
Nelson	Nelson City
New Plymouth	New Plymouth District
New Plymouth	Stratford District
Oamaru	Waitaki District
Otorohanga	Otorohanga District
Palmerston North	Manawatu District
Palmerston North	Palmerston North City
Paraparaumu	Horowhenua District
Paraparaumu	Kapiti Coast District
Pukekohe	Auckland
Pukekohe	Waikato District
Queenstown	Queenstown-Lakes District
Rangiora	Hurunui District
Rangiora	Kaikoura District
Richmond	Tasman District
Rotorua	Rotorua District
Rotorua	South Waikato District
Taumaranui	Ruapehu District
Taumaranui	Waitomo District
Taupo	Taupo District
Tauranga	Tauranga City
Tauranga	Western Bay of Plenty District
Thames	Hauraki District
Thames	Matamata-Piako District
Thames	Thames-Coromandel District
Timaru	Mackenzie District

QSDEP concordance, continued on next page

QSDEP concordance, continued from previous page

QSDEP area	Territorial local authority
Timaru	Timaru District
Timaru	Waimate District
Waipukurau	Central Hawke's Bay District
Wellington City	Lower Hutt City
Wellington City	Porirua City
Wellington City	Upper Hutt City
Wellington City	Wellington City
Westport	Buller District
Whakatane	Kawerau District
Whakatane	Opotiki District
Whakatane	Whakatane District
Whanganui	Rangitikei District
Whanganui	Whanganui District
Whangarei	Kaipara District
Whangarei	Whangarei District
Winton	Gore District
Winton	Southland District

Appendix B

Partial derivatives of QUAIDS elasticities

Non-zero partial derivatives of the expenditure elasticity function, with respect to the model parameters are:

$$\frac{\partial \eta_i^q}{\partial \alpha_i} = -\frac{2\lambda_i \ln p_i}{w_i b(p)} \tag{B.1}$$

$$\frac{\partial \eta_i^q}{\partial \delta_{is}} = -\frac{2\lambda_i z_s \ln p_i}{w_i b(p)} \tag{B.2}$$

$$\frac{\partial \eta_i^q}{\partial \beta_i} = -\frac{2\lambda_i}{w_i \ln p_i b(p)} \left\{ \ln \left[\frac{m}{a(p)} \right] \right\} \tag{B.3}$$

$$\frac{\partial \eta_i^q}{\partial \gamma_i} = -\frac{2\lambda_i \sum_k \gamma_{kj} \ln p_k}{w_i b(p)} \tag{B.4}$$

$$\frac{\partial \eta_i^q}{\partial \lambda_i} = \frac{2}{w_i b(p)} \left\{ \ln \left[\frac{m}{a(p)} \right] \right\} \tag{B.5}$$

Non-zero partial derivatives of the uncompensated elasticity function, with respect to the model parameters are:

$$\begin{aligned} \frac{\partial e_{ij}}{\partial \alpha_j} = -\frac{1}{w_i} \left(\beta_i + \frac{2\lambda_i}{b(p)} \ln \left[\frac{m}{a(p)} \right] \right) + \\ \frac{1}{w_i} \frac{2\lambda_i \ln p_j}{b(p)} \left(\alpha_j + \sum_{i=1}^{S} \delta_{js} z_s + \sum_{k=1}^{N} \gamma_{jk} \ln p_k + \beta_j \ln \left[\frac{m}{a(p)} \right] \right) \end{aligned} \tag{B.6}$$

$$\frac{\partial e_{ij}}{\partial \alpha_{k\notin\{i,j\}}} = \frac{1}{w_i}\frac{2\lambda_i \ln p_k}{b(p)}\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j \ln\left[\frac{m}{a(p)}\right]\right) \tag{B.7}$$

$$\frac{\partial e_{ij}}{\partial \delta_{js}} = -\frac{z_s}{w_i}\left[\beta_i + \frac{2\lambda_i}{b(p)}\ln\left[\frac{m}{a(p)}\right] - \frac{2\lambda_i}{b(p)}\right. \tag{B.8}$$
$$\left.\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j \ln\left[\frac{m}{a(p)}\right]\right)\right]$$

$$\frac{\partial e_{ij}}{\partial \delta_{ks}} = \frac{1}{w_i}\frac{2\lambda_i}{b(p)}z_s \ln p_k\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j \ln\left[\frac{m}{a(p)}\right]\right) \tag{B.9}$$

$$\frac{\partial e_{ij}}{\partial \beta_i} = \frac{1}{w_i}\frac{2\lambda_i}{\ln p_i b(p)}\ln\left[\frac{m}{a(p)}\right]\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k\right) \tag{B.10}$$
$$-\frac{1}{w_i}\frac{\lambda_i}{b(p)}\ln\left[\frac{m}{a(p)}\right]^2\left(1 - \frac{\beta_j}{\ln p_j}\right)$$

$$\frac{\partial e_{ij}}{\partial \beta_{k\notin\{i,j\}}} = \frac{1}{w_i}\frac{2\lambda_i}{\ln p_i b(p)}\ln\left[\frac{m}{a(p)}\right] \tag{B.11}$$
$$\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \frac{\beta_j}{\lambda_i}\ln\left[\frac{m}{a(p)}\right]\right)$$

$$\frac{\partial e_{ij}}{\partial \gamma_{jk}} = \frac{1}{w_i}\left(1 - \beta_i \ln p_k\right) + \frac{1}{w_i}\frac{2\lambda_i}{b(p)}\sum_{k}\gamma_{kj}\ln p_k \tag{B.12}$$
$$\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j \ln\left[\frac{m}{a(p)}\right]\right)$$

$$\frac{\partial e_{ij}}{\partial \lambda_{jk}} = -\frac{2}{w_i b(p)}\ln\left[\frac{m}{a(p)}\right] \tag{B.13}$$
$$\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \frac{1}{2}\beta_j \ln\left[\frac{m}{a(p)}\right]\right)$$

Non-zero partial derivatives of the compensated elasticity function, with respect to the model parameters are:

$$\frac{\partial h_{ij}}{\partial \alpha_j} = -\frac{1}{w_i}\left(\beta_i + \frac{2\lambda_i}{b(p)}\ln\left[\frac{m}{a(p)}\right]\right) + \tag{B.14}$$
$$\frac{1}{w_i}\frac{2\lambda_i \ln p_j}{b(p)}\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j\left(\ln\left[\frac{m}{a(p)}\right] - w_j\right)\right)$$

$$\frac{\partial h_{ij}}{\partial \alpha_{k\notin\{i,j\}}} = \frac{1}{w_i}\frac{2\lambda_i \ln p_k}{b(p)}\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \right. \tag{B.15}$$

$$\left. \beta_j\left(\ln\left[\frac{m}{a(p)}\right] - w_j\right)\right) \tag{B.16}$$

$$\frac{\partial h_{ij}}{\partial \delta_{js}} = -\frac{z_s}{w_i}\left[\beta_i + \frac{2\lambda_i}{b(p)}\ln\left[\frac{m}{a(p)}\right] - \frac{2\lambda_i}{b(p)}\right. \tag{B.17}$$
$$\left.\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j\left(\ln\left[\frac{m}{a(p)}\right] - w_j\right)\right)\right]$$

$$\frac{\partial h_{ij}}{\partial \delta_{ks}} = \frac{1}{w_i}\frac{2\lambda_i}{b(p)}z_s\ln p_k\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j\ln\left[\frac{m}{a(p)}\right] - w_j\right) \tag{B.18}$$

$$\frac{\partial h_{ij}}{\partial \beta_i} = -\frac{1}{w_i}\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k\right) + \tag{B.19}$$
$$\frac{1}{w_i}\frac{2\lambda_i}{\ln p_i b(p)}\ln\left[\frac{m}{a(p)}\right]\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \frac{\beta_j}{\lambda_i}\ln\left[\frac{m}{a(p)}\right] - w_j\right) + \frac{w_j}{w_i}$$

$$\frac{\partial h_{ij}}{\partial \beta_j} = \frac{1}{w_i}\frac{2\lambda_i}{\ln p_i b(p)}\ln\left[\frac{m}{a(p)}\right] \tag{B.20}$$
$$\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \frac{\beta_j}{\lambda_i}\ln\left[\frac{m}{a(p)}\right]\right)$$
$$-\frac{1}{w_i}\frac{\lambda_i}{b(p)}\ln\left[\frac{m}{a(p)}\right]\left(\ln\left[\frac{m}{a(p)}\right] - \frac{\beta_j}{\ln p_j}\ln\left[\frac{m}{a(p)}\right] + \frac{2w_j}{\ln p_j}\right) + \frac{w_j}{w_i}$$

$$\frac{\partial h_{ij}}{\partial \beta_{k\notin\{i,j\}}} = \frac{1}{w_i}\frac{2\lambda_i}{\ln p_i b(p)}\ln\left[\frac{m}{a(p)}\right] \tag{B.21}$$
$$\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \frac{\beta_j}{\lambda_i}\ln\left[\frac{m}{a(p)}\right] - w_j\right) + \frac{w_j}{w_i}$$

$$\frac{\partial h_{ij}}{\partial \gamma_{jk}} = \frac{1}{w_i}\left(1 - \beta_i\ln p_k\right) + \frac{1}{w_i}\frac{2\lambda_i}{b(p)}\sum_k \gamma_{kj}\ln p_k \tag{B.22}$$
$$\left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j\ln\left[\frac{m}{a(p)}\right] - w_j\right)$$

$$\frac{\partial h_{ij}}{\partial \gamma_{lk}} = \frac{1}{w_i}\frac{2\lambda_i}{b(p)}\sum_k \gamma_{lk}\ln p_k \left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \beta_j \ln\left[\frac{m}{a(p)}\right] - w_j\right) \tag{B.23}$$

$$\frac{\partial h_{ij}}{\partial \lambda_{jk}} = -\frac{2}{w_i b(p)}\ln\left[\frac{m}{a(p)}\right] \left(\alpha_j + \sum_{i=1}^{S}\delta_{js}z_s + \sum_{k=1}^{N}\gamma_{jk}\ln p_k + \frac{1}{2}\beta_j \ln\left[\frac{m}{a(p)}\right] - w_j\right) \tag{B.24}$$

Appendix C

Estimation results and alternative models

C.1 Seasonal adjustment

Seasonal adjustment factors were estimated by a linear regression model of household electricity expenditure including included dummy variables for survey months (see Table C.1). The model was estimated with ordinary least squares and on all survey years. Survey year and region of residence were also included as dummy variables. An ANOVA test of model equivalence was used to test the joint importance of the survey month dummies, rejecting ($p < 0.001$) the null of equivalence of models with and without the survey month dummies.

Table C.1: Estimation of monthly seasonal adjustment factors

Dependent: Natural logarithm of electricity expenditure

Variable	Coefficient	Standard error	Significance
Intercept	6.60	0.04	***
Household size	0.20	0.01	***
Number of children	0.001	0.02	
Income	0.000001	0.00	***
Household size x number of children	-0.02	0.00	***

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Variable	Coefficient	Standard error	Significance
February	0.05	0.03	
March	-0.04	0.03	
April	-0.05	0.03	
May	0.03	0.03	
June	0.11	0.03	***
July	0.27	0.03	***
August	0.29	0.03	***
September	0.26	0.03	***
October	0.21	0.03	***
November	0.13	0.03	***
December	0.06	0.03	*
2010	0.15	0.02	***
2013	0.24	0.02	***
2016	0.28	0.02	***
2019	0.25	0.02	***
Auckland	-0.06	0.04	
Waikato	-0.04	0.04	
Bay of Plenty	0.08	0.04	
Gisborne	0.21	0.06	***
Hawke's Bay	0.08	0.05	
Taranaki	-0.13	0.05	*
Manawatu-Whanganui	-0.08	0.04	
Wellington	-0.04	0.04	
West Coast	0.21	0.07	**
Canterbury	0.08	0.04	*
Otago	0.10	0.04	*
Southland	0.18	0.05	***
Tasman	0.04	0.07	
Nelson	0.05	0.05	
Marlborough	0.20	0.06	**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C.2 Demand systems coefficients

The tables below present estimated coefficients for the main quadratic almost ideal demand system (QUAIDS) model and alternative almost ideal demand (AIDS) model.

Table C.2 provides an example of the first stage regression used to correct for potential endogeneity of total expenditure, from which the model residuals are used as an explanatory variable in the demand system estimation.

Table C.2: QUAIDS model first stage regression

Dependent: log of household expenditure

Coefficient	Estimate	Standard error	Significance
Intercept	9.773930	0.0422074	***
Log disposable income	40.870433	0.6328159	***
Square of log of disposable income	13.720517	0.4814514	***
Equivalence scale	0.557705	0.0176261	***
Reference person age	0.013254	0.0013389	***
Square of reference person age	-0.000138	0.0000130	***
Log of 1 + share of income from benefits	-0.477385	0.0207413	***

Data is from HES surveys 2007, 2010, 2013, 2016, 2019

Income terms are orthogonal polynomial terms, implemented with R function *poly*

*p<0.05, **p<0.01, ***p<0.001

Tables C.3 and C.4 present the coefficients of the QUAIDS and AIDS models in full for the versions with both homogeneity and symmetry restrictions. The size of these tables is regrettably unwieldy given the several hundred parameters in each model. As a result each of the tables of coefficients stretch for around a dozen pages. For this reason the coefficients for other models are not presented here though they available in an accompanying data appendix.

Each table lists the type of coefficient that has been estimated. The α_i, β_i, and λ_i coefficients vary only by a single product variable i. The γ_{ij} and δ_{is} (demographic) coefficients vary by expenditure share product variable i and counterpart product price variable j and demographic variable s.

In the tables of coefficients products have been summarised with a shortened product code. The codes are: accom = Accommodation; air = Air transport; alc = Alcohol and tobacco; cloth = Clothing; comm = Communications; cont = Household contents; take = Takeaways and eating out; educ = Education; elec = Electricity; food = Groceries; hlth = Health; insur = Insurance; othr = Miscellaneous;mort = Mortgage interest; nrg = Energy excluding electricity; rec = Recreation; trans = Transport.

Table C.3: Coefficients of QUAIDS model

Dependent: Expenditure share by product

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
α_i	comm		0.123924	0.0074671	***
α_i	cont		-0.056785	0.0110883	***
α_i	elec		0.249064	0.0075418	***
α_i	food		0.033184	0.0176932	
α_i	hlth		-0.050793	0.0098421	***
α_i	accom		1.034077	0.0335199	***
α_i	insur		-0.046849	0.0099698	***
α_i	othr		-0.094676	0.0138595	***
α_i	rec		-0.116523	0.0159993	***
α_i	take		-0.028687	0.0096994	**
α_i	trans		-0.097158	0.0132689	***
α_i	air		-0.009889	0.0102144	
α_i	nrg		0.010432	0.0043000	*
α_i	alc		-0.047179	0.0102929	***
α_i	educ		0.049082	0.0080056	***
α_i	cloth		-0.036823	0.0101083	***
α_i	mort		0.085601	0.0211540	***
β_i	comm		-0.030805	0.0035820	***
β_i	cont		0.035862	0.0053048	***
β_i	elec		-0.101184	0.0036414	***
β_i	food		0.002105	0.0084109	
β_i	hlth		0.032962	0.0046888	***
β_i	accom		-0.241588	0.0159085	***
β_i	insur		0.029720	0.0047818	***

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
β_i	othr		0.076462	0.0066138	***
β_i	rec		0.074090	0.0075982	***
β_i	take		0.044432	0.0046175	***
β_i	trans		0.064051	0.0063313	***
β_i	air		0.009418	0.0048828	
β_i	nrg		-0.006885	0.0021435	**
β_i	alc		0.035019	0.0049166	***
β_i	educ		-0.019430	0.0038347	***
β_i	cloth		0.021202	0.0048273	***
β_i	mort		-0.025428	0.0101950	*
λ_i	comm		0.001565	0.0004138	***
λ_i	cont		-0.002881	0.0006164	***
λ_i	elec		0.008839	0.0004190	***
λ_i	food		-0.007775	0.0009804	***
λ_i	hlth		-0.002983	0.0005453	***
λ_i	accom		0.023538	0.0018596	***
λ_i	insur		-0.002745	0.0005556	***
λ_i	othr		-0.005745	0.0007696	***
λ_i	rec		-0.004494	0.0008863	***
λ_i	take		-0.003408	0.0005372	***
λ_i	trans		-0.010235	0.0007367	***
λ_i	air		0.001449	0.0005663	*
λ_i	nrg		0.000744	0.0002393	**
λ_i	alc		-0.003921	0.0005712	***
λ_i	educ		0.002407	0.0004434	***
λ_i	cloth		-0.000788	0.0005599	
λ_i	mort		0.006436	0.0011778	***
γ_{ij}	comm	comm	0.002747	0.0082127	
γ_{ij}	comm	cont	0.006663	0.0083074	
γ_{ij}	comm	elec	0.034291	0.0058805	***
γ_{ij}	comm	food	0.001436	0.0045461	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	comm	hlth	-0.026820	0.0119118	*
γ_{ij}	comm	accom	-0.021032	0.0197747	
γ_{ij}	comm	insur	-0.009105	0.0102270	
γ_{ij}	comm	othr	-0.005256	0.0078412	
γ_{ij}	comm	rec	0.027610	0.0160657	
γ_{ij}	comm	take	-0.035136	0.0120904	**
γ_{ij}	comm	trans	0.017613	0.0060748	**
γ_{ij}	comm	air	-0.024504	0.0064678	***
γ_{ij}	comm	nrg	0.007106	0.0066961	
γ_{ij}	comm	alc	0.020151	0.0101360	*
γ_{ij}	comm	educ	-0.001676	0.0093714	
γ_{ij}	comm	cloth	0.019530	0.0104414	
γ_{ij}	comm	mort	-0.013618	0.0088660	
γ_{ij}	cont	comm	0.006663	0.0083074	
γ_{ij}	cont	cont	-0.057289	0.0167229	***
γ_{ij}	cont	elec	-0.042494	0.0082667	***
γ_{ij}	cont	food	0.009353	0.0054670	
γ_{ij}	cont	hlth	-0.034657	0.0153879	*
γ_{ij}	cont	accom	0.038434	0.0294880	
γ_{ij}	cont	insur	0.026964	0.0137180	*
γ_{ij}	cont	othr	-0.023585	0.0106172	*
γ_{ij}	cont	rec	-0.028216	0.0193955	
γ_{ij}	cont	take	0.052015	0.0171244	**
γ_{ij}	cont	trans	0.008651	0.0080783	
γ_{ij}	cont	air	0.029618	0.0091274	**
γ_{ij}	cont	nrg	-0.014119	0.0090226	
γ_{ij}	cont	alc	-0.029035	0.0129534	*
γ_{ij}	cont	educ	0.016118	0.0120397	
γ_{ij}	cont	cloth	0.008870	0.0145246	
γ_{ij}	cont	mort	0.032708	0.0115318	**
γ_{ij}	elec	comm	0.034291	0.0058805	***

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	elec	cont	-0.042494	0.0082667	***
γ_{ij}	elec	elec	-0.010083	0.0075284	
γ_{ij}	elec	food	0.007994	0.0046335	
γ_{ij}	elec	hlth	0.029270	0.0094516	**
γ_{ij}	elec	accom	-0.017442	0.0236890	
γ_{ij}	elec	insur	-0.005430	0.0092864	
γ_{ij}	elec	othr	-0.000783	0.0084001	
γ_{ij}	elec	rec	-0.029207	0.0139026	*
γ_{ij}	elec	take	0.043799	0.0099587	***
γ_{ij}	elec	trans	0.003082	0.0059881	
γ_{ij}	elec	air	-0.000853	0.0065138	
γ_{ij}	elec	nrg	0.000699	0.0048471	
γ_{ij}	elec	alc	-0.009142	0.0081650	
γ_{ij}	elec	educ	0.036834	0.0071803	***
γ_{ij}	elec	cloth	-0.000009	0.0087902	
γ_{ij}	elec	mort	-0.040525	0.0082489	***
γ_{ij}	food	comm	0.001436	0.0045461	
γ_{ij}	food	cont	0.009353	0.0054670	
γ_{ij}	food	elec	0.007994	0.0046335	
γ_{ij}	food	food	0.003794	0.0081302	
γ_{ij}	food	hlth	-0.011349	0.0050522	*
γ_{ij}	food	accom	-0.022236	0.0153088	
γ_{ij}	food	insur	0.001333	0.0054479	
γ_{ij}	food	othr	-0.003997	0.0064938	
γ_{ij}	food	rec	0.009761	0.0079531	
γ_{ij}	food	take	0.002625	0.0051714	
γ_{ij}	food	trans	-0.003679	0.0055790	
γ_{ij}	food	air	-0.007176	0.0050440	
γ_{ij}	food	nrg	0.000432	0.0033971	
γ_{ij}	food	alc	0.015608	0.0050789	**
γ_{ij}	food	educ	-0.002361	0.0043601	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	food	cloth	0.002547	0.0051687	
γ_{ij}	food	mort	-0.004084	0.0092812	
γ_{ij}	hlth	comm	-0.026820	0.0119118	*
γ_{ij}	hlth	cont	-0.034657	0.0153879	*
γ_{ij}	hlth	elec	0.029270	0.0094516	**
γ_{ij}	hlth	food	-0.011349	0.0050522	*
γ_{ij}	hlth	hlth	-0.073234	0.0333069	*
γ_{ij}	hlth	accom	-0.023742	0.0323277	
γ_{ij}	hlth	insur	-0.042837	0.0187170	*
γ_{ij}	hlth	othr	0.029883	0.0109770	**
γ_{ij}	hlth	rec	0.073089	0.0297022	*
γ_{ij}	hlth	take	-0.027625	0.0271919	
γ_{ij}	hlth	trans	0.012445	0.0093674	
γ_{ij}	hlth	air	-0.019955	0.0110201	
γ_{ij}	hlth	nrg	-0.002744	0.0116212	
γ_{ij}	hlth	alc	0.063857	0.0179659	***
γ_{ij}	hlth	educ	-0.033004	0.0189469	
γ_{ij}	hlth	cloth	0.084287	0.0213368	***
γ_{ij}	hlth	mort	0.003136	0.0122265	
γ_{ij}	accom	comm	-0.021032	0.0197747	
γ_{ij}	accom	cont	0.038434	0.0294880	
γ_{ij}	accom	elec	-0.017442	0.0236890	
γ_{ij}	accom	food	-0.022236	0.0153088	
γ_{ij}	accom	hlth	-0.023742	0.0323277	
γ_{ij}	accom	accom	0.107462	0.0558840	
γ_{ij}	accom	insur	0.003693	0.0302846	
γ_{ij}	accom	othr	0.023958	0.0261640	
γ_{ij}	accom	rec	0.010239	0.0345496	
γ_{ij}	accom	take	-0.047936	0.0349334	
γ_{ij}	accom	trans	-0.044972	0.0208450	*
γ_{ij}	accom	air	0.040234	0.0238503	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	accom	nrg	0.046161	0.0267487	
γ_{ij}	accom	alc	0.048852	0.0295500	
γ_{ij}	accom	educ	-0.054655	0.0280603	
γ_{ij}	accom	cloth	-0.041899	0.0317106	
γ_{ij}	accom	mort	-0.045119	0.0329418	
γ_{ij}	insur	comm	-0.009105	0.0102270	
γ_{ij}	insur	cont	0.026964	0.0137180	*
γ_{ij}	insur	elec	-0.005430	0.0092864	
γ_{ij}	insur	food	0.001333	0.0054479	
γ_{ij}	insur	hlth	-0.042837	0.0187170	*
γ_{ij}	insur	accom	0.003693	0.0302846	
γ_{ij}	insur	insur	0.017390	0.0222449	
γ_{ij}	insur	othr	-0.026842	0.0111619	*
γ_{ij}	insur	rec	-0.009739	0.0224744	
γ_{ij}	insur	take	0.007370	0.0199688	
γ_{ij}	insur	trans	-0.001766	0.0088811	
γ_{ij}	insur	air	-0.003373	0.0101262	
γ_{ij}	insur	nrg	-0.004810	0.0109274	
γ_{ij}	insur	alc	0.000654	0.0164806	
γ_{ij}	insur	educ	0.028040	0.0159884	
γ_{ij}	insur	cloth	0.007526	0.0167912	
γ_{ij}	insur	mort	0.010933	0.0129980	
γ_{ij}	othr	comm	-0.005256	0.0078412	
γ_{ij}	othr	cont	-0.023585	0.0106172	*
γ_{ij}	othr	elec	-0.000783	0.0084001	
γ_{ij}	othr	food	-0.003997	0.0064938	
γ_{ij}	othr	hlth	0.029883	0.0109770	**
γ_{ij}	othr	accom	0.023958	0.0261640	
γ_{ij}	othr	insur	-0.026842	0.0111619	*
γ_{ij}	othr	othr	0.036117	0.0154230	*
γ_{ij}	othr	rec	0.015413	0.0156922	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	othr	take	0.003774	0.0115663	
γ_{ij}	othr	trans	-0.024668	0.0083277	**
γ_{ij}	othr	air	-0.024836	0.0088175	**
γ_{ij}	othr	nrg	0.004480	0.0079846	
γ_{ij}	othr	alc	-0.010230	0.0101191	
γ_{ij}	othr	educ	-0.011020	0.0090475	
γ_{ij}	othr	cloth	0.013600	0.0109341	
γ_{ij}	othr	mort	0.003994	0.0129869	
γ_{ij}	rec	comm	0.027610	0.0160657	
γ_{ij}	rec	cont	-0.028216	0.0193955	
γ_{ij}	rec	elec	-0.029207	0.0139026	*
γ_{ij}	rec	food	0.009761	0.0079531	
γ_{ij}	rec	hlth	0.073089	0.0297022	*
γ_{ij}	rec	accom	0.010239	0.0345496	
γ_{ij}	rec	insur	-0.009739	0.0224744	
γ_{ij}	rec	othr	0.015413	0.0156922	
γ_{ij}	rec	rec	0.001909	0.0447019	
γ_{ij}	rec	take	0.080395	0.0330807	*
γ_{ij}	rec	trans	0.014535	0.0131146	
γ_{ij}	rec	air	0.058371	0.0150279	***
γ_{ij}	rec	nrg	-0.003906	0.0169572	
γ_{ij}	rec	alc	-0.085904	0.0236679	***
γ_{ij}	rec	educ	-0.032084	0.0246395	
γ_{ij}	rec	cloth	-0.089262	0.0239002	***
γ_{ij}	rec	mort	-0.013002	0.0184709	
γ_{ij}	take	comm	-0.035136	0.0120904	**
γ_{ij}	take	cont	0.052015	0.0171244	**
γ_{ij}	take	elec	0.043799	0.0099587	***
γ_{ij}	take	food	0.002625	0.0051714	
γ_{ij}	take	hlth	-0.027625	0.0271919	
γ_{ij}	take	accom	-0.047936	0.0349334	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	take	insur	0.007370	0.0199688	
γ_{ij}	take	othr	0.003774	0.0115663	
γ_{ij}	take	rec	0.080395	0.0330807	*
γ_{ij}	take	take	-0.004167	0.0418888	
γ_{ij}	take	trans	0.004537	0.0096748	
γ_{ij}	take	air	-0.031881	0.0119692	**
γ_{ij}	take	nrg	-0.002618	0.0132802	
γ_{ij}	take	alc	-0.016165	0.0213665	
γ_{ij}	take	educ	-0.020309	0.0208079	
γ_{ij}	take	cloth	-0.018152	0.0210336	
γ_{ij}	take	mort	0.009475	0.0125671	
γ_{ij}	trans	comm	0.017613	0.0060748	**
γ_{ij}	trans	cont	0.008651	0.0080783	
γ_{ij}	trans	elec	0.003082	0.0059881	
γ_{ij}	trans	food	-0.003679	0.0055790	
γ_{ij}	trans	hlth	0.012445	0.0093674	
γ_{ij}	trans	accom	-0.044972	0.0208450	*
γ_{ij}	trans	insur	-0.001766	0.0088811	
γ_{ij}	trans	othr	-0.024668	0.0083277	**
γ_{ij}	trans	rec	0.014535	0.0131146	
γ_{ij}	trans	take	0.004537	0.0096748	
γ_{ij}	trans	trans	0.072567	0.0091086	***
γ_{ij}	trans	air	-0.003132	0.0069383	
γ_{ij}	trans	nrg	-0.000979	0.0055330	
γ_{ij}	trans	alc	-0.027050	0.0080627	***
γ_{ij}	trans	educ	0.008988	0.0071876	
γ_{ij}	trans	cloth	-0.022074	0.0084771	**
γ_{ij}	trans	mort	-0.014097	0.0103495	
γ_{ij}	air	comm	-0.024504	0.0064678	***
γ_{ij}	air	cont	0.029618	0.0091274	**
γ_{ij}	air	elec	-0.000853	0.0065138	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	air	food	-0.007176	0.0050440	
γ_{ij}	air	hlth	-0.019955	0.0110201	
γ_{ij}	air	accom	0.040234	0.0238503	
γ_{ij}	air	insur	-0.003373	0.0101262	
γ_{ij}	air	othr	-0.024836	0.0088175	**
γ_{ij}	air	rec	0.058371	0.0150279	***
γ_{ij}	air	take	-0.031881	0.0119692	**
γ_{ij}	air	trans	-0.003132	0.0069383	
γ_{ij}	air	air	0.002104	0.0102292	
γ_{ij}	air	nrg	-0.001584	0.0065774	
γ_{ij}	air	alc	0.034563	0.0096077	***
γ_{ij}	air	educ	-0.036786	0.0092848	***
γ_{ij}	air	cloth	-0.024293	0.0104592	*
γ_{ij}	air	mort	0.013484	0.0093518	
γ_{ij}	nrg	comm	0.007106	0.0066961	
γ_{ij}	nrg	cont	-0.014119	0.0090226	
γ_{ij}	nrg	elec	0.000699	0.0048471	
γ_{ij}	nrg	food	0.000432	0.0033971	
γ_{ij}	nrg	hlth	-0.002744	0.0116212	
γ_{ij}	nrg	accom	0.046161	0.0267487	
γ_{ij}	nrg	insur	-0.004810	0.0109274	
γ_{ij}	nrg	othr	0.004480	0.0079846	
γ_{ij}	nrg	rec	-0.003906	0.0169572	
γ_{ij}	nrg	take	-0.002618	0.0132802	
γ_{ij}	nrg	trans	-0.000979	0.0055330	
γ_{ij}	nrg	air	-0.001584	0.0065774	
γ_{ij}	nrg	nrg	0.006360	0.0070113	
γ_{ij}	nrg	alc	-0.039523	0.0095277	***
γ_{ij}	nrg	educ	0.014606	0.0087138	
γ_{ij}	nrg	cloth	0.002910	0.0104588	
γ_{ij}	nrg	mort	-0.012472	0.0069418	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	alc	comm	0.020151	0.0101360	*
γ_{ij}	alc	cont	-0.029035	0.0129534	*
γ_{ij}	alc	elec	-0.009142	0.0081650	
γ_{ij}	alc	food	0.015608	0.0050789	**
γ_{ij}	alc	hlth	0.063857	0.0179659	***
γ_{ij}	alc	accom	0.048852	0.0295500	
γ_{ij}	alc	insur	0.000654	0.0164806	
γ_{ij}	alc	othr	-0.010230	0.0101191	
γ_{ij}	alc	rec	-0.085904	0.0236679	***
γ_{ij}	alc	take	-0.016165	0.0213665	
γ_{ij}	alc	trans	-0.027050	0.0080627	***
γ_{ij}	alc	air	0.034563	0.0096077	***
γ_{ij}	alc	nrg	-0.039523	0.0095277	***
γ_{ij}	alc	alc	0.035514	0.0204260	
γ_{ij}	alc	educ	-0.028684	0.0144334	*
γ_{ij}	alc	cloth	0.007556	0.0155659	
γ_{ij}	alc	mort	0.018980	0.0113418	
γ_{ij}	educ	comm	-0.001676	0.0093714	
γ_{ij}	educ	cont	0.016118	0.0120397	
γ_{ij}	educ	elec	0.036834	0.0071803	***
γ_{ij}	educ	food	-0.002361	0.0043601	
γ_{ij}	educ	hlth	-0.033004	0.0189469	
γ_{ij}	educ	accom	-0.054655	0.0280603	
γ_{ij}	educ	insur	0.028040	0.0159884	
γ_{ij}	educ	othr	-0.011020	0.0090475	
γ_{ij}	educ	rec	-0.032084	0.0246395	
γ_{ij}	educ	take	-0.020309	0.0208079	
γ_{ij}	educ	trans	0.008988	0.0071876	
γ_{ij}	educ	air	-0.036786	0.0092848	***
γ_{ij}	educ	nrg	0.014606	0.0087138	
γ_{ij}	educ	alc	-0.028684	0.0144334	*

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	educ	educ	0.065318	0.0200554	**
γ_{ij}	educ	cloth	0.035531	0.0153801	*
γ_{ij}	educ	mort	0.015145	0.0092847	
γ_{ij}	cloth	comm	0.019530	0.0104414	
γ_{ij}	cloth	cont	0.008870	0.0145246	
γ_{ij}	cloth	elec	-0.000009	0.0087902	
γ_{ij}	cloth	food	0.002547	0.0051687	
γ_{ij}	cloth	hlth	0.084287	0.0213368	***
γ_{ij}	cloth	accom	-0.041899	0.0317106	
γ_{ij}	cloth	insur	0.007526	0.0167912	
γ_{ij}	cloth	othr	0.013600	0.0109341	
γ_{ij}	cloth	rec	-0.089262	0.0239002	***
γ_{ij}	cloth	take	-0.018152	0.0210336	
γ_{ij}	cloth	trans	-0.022074	0.0084771	**
γ_{ij}	cloth	air	-0.024293	0.0104592	*
γ_{ij}	cloth	nrg	0.002910	0.0104588	
γ_{ij}	cloth	alc	0.007556	0.0155659	
γ_{ij}	cloth	educ	0.035531	0.0153801	*
γ_{ij}	cloth	cloth	-0.004523	0.0234485	
γ_{ij}	cloth	mort	0.017854	0.0118379	
γ_{ij}	mort	comm	-0.013618	0.0088660	
γ_{ij}	mort	cont	0.032708	0.0115318	**
γ_{ij}	mort	elec	-0.040525	0.0082489	***
γ_{ij}	mort	food	-0.004084	0.0092812	
γ_{ij}	mort	hlth	0.003136	0.0122265	
γ_{ij}	mort	accom	-0.045119	0.0329418	
γ_{ij}	mort	insur	0.010933	0.0129980	
γ_{ij}	mort	othr	0.003994	0.0129869	
γ_{ij}	mort	rec	-0.013002	0.0184709	
γ_{ij}	mort	take	0.009475	0.0125671	
γ_{ij}	mort	trans	-0.014097	0.0103495	

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	mort	air	0.013484	0.0093518	
γ_{ij}	mort	nrg	-0.012472	0.0069418	
γ_{ij}	mort	alc	0.018980	0.0113418	
γ_{ij}	mort	educ	0.015145	0.0092847	
γ_{ij}	mort	cloth	0.017854	0.0118379	
γ_{ij}	mort	mort	0.017208	0.0184944	
δ_{is}	comm	size	0.006121	0.0016174	***
δ_{is}	comm	age	-0.000081	0.0000956	
δ_{is}	comm	age_sq	0.000002	0.0000009	*
δ_{is}	comm	benefit	-0.008505	0.0018717	***
δ_{is}	comm	resid	0.000171	0.0012694	
δ_{is}	cont	size	-0.010967	0.0024844	***
δ_{is}	cont	age	-0.000046	0.0001476	
δ_{is}	cont	age_sq	0.000005	0.0000014	***
δ_{is}	cont	benefit	0.002191	0.0028582	
δ_{is}	cont	resid	-0.000445	0.0019306	
δ_{is}	elec	size	0.026367	0.0016464	***
δ_{is}	elec	age	0.000315	0.0000969	**
δ_{is}	elec	age_sq	-0.000001	0.0000009	
δ_{is}	elec	benefit	0.006351	0.0018996	***
δ_{is}	elec	resid	-0.001164	0.0012915	
δ_{is}	food	size	0.128338	0.0039422	***
δ_{is}	food	age	0.000978	0.0002352	***
δ_{is}	food	age_sq	-0.000001	0.0000023	
δ_{is}	food	benefit	0.005302	0.0045566	
δ_{is}	food	resid	0.015042	0.0030649	***
δ_{is}	hlth	size	-0.009891	0.0022161	***
δ_{is}	hlth	age	-0.000312	0.0001317	*
δ_{is}	hlth	age_sq	0.000009	0.0000013	***
δ_{is}	hlth	benefit	0.011282	0.0025471	***
δ_{is}	hlth	resid	-0.000360	0.0017199	

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Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
δ_{is}	accom	size	-0.057117	0.0076316	***
δ_{is}	accom	age	-0.002035	0.0004563	***
δ_{is}	accom	age_sq	-0.000019	0.0000044	***
δ_{is}	accom	benefit	0.089030	0.0087693	***
δ_{is}	accom	resid	0.055003	0.0059020	***
δ_{is}	insur	size	-0.014605	0.0022374	***
δ_{is}	insur	age	0.001023	0.0001329	***
δ_{is}	insur	age_sq	0.000001	0.0000013	
δ_{is}	insur	benefit	-0.019033	0.0025746	***
δ_{is}	insur	resid	-0.019023	0.0017382	***
δ_{is}	othr	size	-0.030439	0.0031126	***
δ_{is}	othr	age	0.000159	0.0001853	
δ_{is}	othr	age_sq	-0.000001	0.0000018	
δ_{is}	othr	benefit	-0.014199	0.0035850	***
δ_{is}	othr	resid	-0.026949	0.0024173	***
δ_{is}	rec	size	-0.033232	0.0036197	***
δ_{is}	rec	age	-0.000411	0.0002158	
δ_{is}	rec	age_sq	0.000014	0.0000021	***
δ_{is}	rec	benefit	-0.003811	0.0041615	
δ_{is}	rec	resid	-0.013597	0.0028050	***
δ_{is}	take	size	-0.007510	0.0021758	***
δ_{is}	take	age	-0.001427	0.0001294	***
δ_{is}	take	age_sq	0.000014	0.0000013	***
δ_{is}	take	benefit	-0.010661	0.0025033	***
δ_{is}	take	resid	-0.014530	0.0016889	***
δ_{is}	trans	size	0.031183	0.0029712	***
δ_{is}	trans	age	0.001084	0.0001770	***
δ_{is}	trans	age_sq	-0.000008	0.0000017	***
δ_{is}	trans	benefit	-0.019802	0.0034259	***
δ_{is}	trans	resid	0.003345	0.0023089	
δ_{is}	air	size	-0.019379	0.0022623	***

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Coefficients of QUAIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
δ_{is}	air	age	-0.000028	0.0001342	
δ_{is}	air	age_sq	0.000002	0.0000013	
δ_{is}	air	benefit	-0.000655	0.0026087	
δ_{is}	air	resid	-0.004142	0.0017632	*
δ_{is}	nrg	size	0.003966	0.0008669	***
δ_{is}	nrg	age	0.000236	0.0000487	***
δ_{is}	nrg	age_sq	-0.000002	0.0000005	***
δ_{is}	nrg	benefit	0.003065	0.0010004	**
δ_{is}	nrg	resid	-0.002149	0.0007004	**
δ_{is}	alc	size	-0.014455	0.0023094	***
δ_{is}	alc	age	0.000717	0.0001372	***
δ_{is}	alc	age_sq	-0.000007	0.0000013	***
δ_{is}	alc	benefit	0.004700	0.0026582	
δ_{is}	alc	resid	-0.009415	0.0017948	***
δ_{is}	educ	size	0.020812	0.0017668	***
δ_{is}	educ	age	-0.000741	0.0001044	***
δ_{is}	educ	age_sq	0.000004	0.0000010	***
δ_{is}	educ	benefit	-0.005398	0.0020358	**
δ_{is}	educ	resid	0.006304	0.0013798	***
δ_{is}	cloth	size	0.000197	0.0022564	
δ_{is}	cloth	age	-0.000469	0.0001338	***
δ_{is}	cloth	age_sq	0.000006	0.0000013	***
δ_{is}	cloth	benefit	0.000847	0.0025948	
δ_{is}	cloth	resid	-0.001253	0.0017548	
δ_{is}	mort	size	-0.019387	0.0045855	***
δ_{is}	mort	age	0.001038	0.0002712	***
δ_{is}	mort	age_sq	-0.000018	0.0000026	***
δ_{is}	mort	benefit	-0.040704	0.0053252	***
δ_{is}	mort	resid	0.013164	0.0035995	***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C.4: Coefficients of AIDS model

Dependent: Expenditure share by product					
Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
α_i	comm		0.099597	0.004028	***
α_i	cont		-0.015929	0.006257	*
α_i	elec		0.128629	0.003914	***
α_i	food		0.153133	0.009776	***
α_i	hlth		-0.006218	0.005661	
α_i	accom		0.673984	0.019169	***
α_i	insur		-0.005516	0.005690	
α_i	othr		-0.008173	0.007844	
α_i	rec		-0.054742	0.009210	***
α_i	take		0.018406	0.005528	***
α_i	trans		0.052384	0.007521	***
α_i	air		-0.028785	0.005633	***
α_i	nrg		-0.001182	0.001765	
α_i	alc		0.010298	0.005849	
α_i	educ		0.010830	0.004416	*
α_i	cloth		-0.024996	0.005755	***
α_i	mort		-0.001722	0.011480	
β_i	comm		-0.018547	0.001133	***
β_i	cont		0.013632	0.001757	***
β_i	elec		-0.031664	0.001106	***
β_i	food		-0.061822	0.002769	***
β_i	hlth		0.008741	0.001581	***
β_i	accom		-0.047713	0.005390	***
β_i	insur		0.007593	0.001581	***
β_i	othr		0.030093	0.002210	***
β_i	rec		0.038886	0.002578	***
β_i	take		0.017312	0.001537	***
β_i	trans		-0.017524	0.002126	***
β_i	air		0.019621	0.001588	***
β_i	nrg		-0.000661	0.000497	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
β_i	alc		0.003870	0.001643	*
β_i	educ		-0.000634	0.001237	
β_i	cloth		0.014981	0.001612	***
β_i	mort		0.023836	0.003256	***
γ_{ij}	comm	comm	-0.000320	0.008392	
γ_{ij}	comm	cont	0.009251	0.008496	
γ_{ij}	comm	elec	0.028512	0.005877	***
γ_{ij}	comm	food	0.003298	0.004592	
γ_{ij}	comm	hlth	-0.025947	0.012284	*
γ_{ij}	comm	accom	-0.035058	0.019613	
γ_{ij}	comm	insur	-0.007476	0.010476	
γ_{ij}	comm	othr	0.001635	0.008060	
γ_{ij}	comm	rec	0.033066	0.016560	*
γ_{ij}	comm	take	-0.035398	0.012409	**
γ_{ij}	comm	trans	0.017449	0.006172	**
γ_{ij}	comm	air	-0.025679	0.006624	***
γ_{ij}	comm	nrg	0.014103	0.006779	*
γ_{ij}	comm	alc	0.018311	0.010504	
γ_{ij}	comm	educ	-0.002985	0.009631	
γ_{ij}	comm	cloth	0.019868	0.010679	
γ_{ij}	comm	mort	-0.012630	0.009039	
γ_{ij}	cont	comm	0.009251	0.008496	
γ_{ij}	cont	cont	-0.058771	0.017117	***
γ_{ij}	cont	elec	-0.034853	0.008353	***
γ_{ij}	cont	food	0.014679	0.005581	**
γ_{ij}	cont	hlth	-0.033967	0.015776	*
γ_{ij}	cont	accom	0.039362	0.029281	
γ_{ij}	cont	insur	0.026533	0.014019	
γ_{ij}	cont	othr	-0.030099	0.010977	**
γ_{ij}	cont	rec	-0.031719	0.019844	
γ_{ij}	cont	take	0.051446	0.017412	**

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	cont	trans	0.006663	0.008259	
γ_{ij}	cont	air	0.023588	0.009350	*
γ_{ij}	cont	nrg	-0.008799	0.009109	
γ_{ij}	cont	alc	-0.038113	0.013302	**
γ_{ij}	cont	educ	0.024311	0.012283	*
γ_{ij}	cont	cloth	0.008385	0.014830	
γ_{ij}	cont	mort	0.032104	0.011731	**
γ_{ij}	elec	comm	0.028512	0.005877	***
γ_{ij}	elec	cont	-0.034853	0.008353	***
γ_{ij}	elec	elec	-0.016165	0.007292	*
γ_{ij}	elec	food	0.003910	0.004406	
γ_{ij}	elec	hlth	0.021898	0.009628	*
γ_{ij}	elec	accom	-0.021386	0.023309	
γ_{ij}	elec	insur	-0.000866	0.009373	
γ_{ij}	elec	othr	0.009218	0.008519	
γ_{ij}	elec	rec	-0.018943	0.014114	
γ_{ij}	elec	take	0.045470	0.009997	***
γ_{ij}	elec	trans	-0.002562	0.005972	
γ_{ij}	elec	air	0.005792	0.006536	
γ_{ij}	elec	nrg	-0.000026	0.004585	
γ_{ij}	elec	alc	-0.010012	0.008297	
γ_{ij}	elec	educ	0.038049	0.007226	***
γ_{ij}	elec	cloth	-0.007259	0.008920	
γ_{ij}	elec	mort	-0.040776	0.008017	***
γ_{ij}	food	comm	0.003298	0.004592	
γ_{ij}	food	cont	0.014679	0.005581	**
γ_{ij}	food	elec	0.003910	0.004406	
γ_{ij}	food	food	0.001843	0.008264	
γ_{ij}	food	hlth	-0.010214	0.005170	*
γ_{ij}	food	accom	-0.033617	0.014483	*
γ_{ij}	food	insur	-0.000949	0.005549	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	food	othr	-0.001386	0.006537	
γ_{ij}	food	rec	0.011040	0.008037	
γ_{ij}	food	take	0.001901	0.005205	
γ_{ij}	food	trans	-0.003804	0.005649	
γ_{ij}	food	air	-0.004086	0.005155	
γ_{ij}	food	nrg	0.002427	0.003365	
γ_{ij}	food	alc	0.017892	0.005193	***
γ_{ij}	food	educ	-0.003325	0.004440	
γ_{ij}	food	cloth	0.002132	0.005320	
γ_{ij}	food	mort	-0.001740	0.009476	
γ_{ij}	hlth	comm	-0.025947	0.012284	*
γ_{ij}	hlth	cont	-0.033967	0.015776	*
γ_{ij}	hlth	elec	0.021898	0.009628	*
γ_{ij}	hlth	food	-0.010214	0.005170	*
γ_{ij}	hlth	hlth	-0.071241	0.034340	*
γ_{ij}	hlth	accom	-0.024256	0.032432	
γ_{ij}	hlth	insur	-0.045844	0.019162	*
γ_{ij}	hlth	othr	0.028383	0.011426	*
γ_{ij}	hlth	rec	0.069118	0.030679	*
γ_{ij}	hlth	take	-0.022764	0.027876	
γ_{ij}	hlth	trans	0.014280	0.009587	
γ_{ij}	hlth	air	-0.026500	0.011328	*
γ_{ij}	hlth	nrg	0.001647	0.011826	
γ_{ij}	hlth	alc	0.058993	0.018718	**
γ_{ij}	hlth	educ	-0.024258	0.019468	
γ_{ij}	hlth	cloth	0.089274	0.021788	***
γ_{ij}	hlth	mort	0.001400	0.012469	
γ_{ij}	accom	comm	-0.035058	0.019613	
γ_{ij}	accom	cont	0.039362	0.029281	
γ_{ij}	accom	elec	-0.021386	0.023309	
γ_{ij}	accom	food	-0.033617	0.014483	*

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	accom	hlth	-0.024256	0.032432	
γ_{ij}	accom	accom	0.074639	0.054133	
γ_{ij}	accom	insur	0.006060	0.030346	
γ_{ij}	accom	othr	0.041916	0.026030	
γ_{ij}	accom	rec	0.030445	0.034546	
γ_{ij}	accom	take	-0.044198	0.035036	
γ_{ij}	accom	trans	-0.054926	0.020356	**
γ_{ij}	accom	air	0.044377	0.023657	
γ_{ij}	accom	nrg	0.054486	0.026520	*
γ_{ij}	accom	alc	0.048067	0.029572	
γ_{ij}	accom	educ	-0.052957	0.028012	
γ_{ij}	accom	cloth	-0.036237	0.031627	
γ_{ij}	accom	mort	-0.036719	0.031768	
γ_{ij}	insur	comm	-0.007476	0.010476	
γ_{ij}	insur	cont	0.026533	0.014019	
γ_{ij}	insur	elec	-0.000866	0.009373	
γ_{ij}	insur	food	-0.000949	0.005549	
γ_{ij}	insur	hlth	-0.045844	0.019162	*
γ_{ij}	insur	accom	0.006060	0.030346	
γ_{ij}	insur	insur	0.014912	0.022751	
γ_{ij}	insur	othr	-0.027171	0.011552	*
γ_{ij}	insur	rec	-0.004697	0.023054	
γ_{ij}	insur	take	0.008312	0.020337	
γ_{ij}	insur	trans	-0.002491	0.009045	
γ_{ij}	insur	air	-0.005986	0.010373	
γ_{ij}	insur	nrg	-0.004391	0.011056	
γ_{ij}	insur	alc	0.003713	0.017024	
γ_{ij}	insur	educ	0.027203	0.016308	
γ_{ij}	insur	cloth	0.006692	0.017094	
γ_{ij}	insur	mort	0.006447	0.013236	
γ_{ij}	othr	comm	0.001635	0.008060	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	othr	cont	-0.030099	0.010977	**
γ_{ij}	othr	elec	0.009218	0.008519	
γ_{ij}	othr	food	-0.001386	0.006537	
γ_{ij}	othr	hlth	0.028383	0.011426	*
γ_{ij}	othr	accom	0.041916	0.026030	
γ_{ij}	othr	insur	-0.027171	0.011552	*
γ_{ij}	othr	othr	0.022294	0.015906	
γ_{ij}	othr	rec	0.006537	0.016216	
γ_{ij}	othr	take	-0.002908	0.011935	
γ_{ij}	othr	trans	-0.019718	0.008513	*
γ_{ij}	othr	air	-0.025995	0.009073	**
γ_{ij}	othr	nrg	0.006150	0.008152	
γ_{ij}	othr	alc	-0.008246	0.010515	
γ_{ij}	othr	educ	-0.009970	0.009344	
γ_{ij}	othr	cloth	0.006767	0.011362	
γ_{ij}	othr	mort	0.002592	0.013150	
γ_{ij}	rec	comm	0.033066	0.016560	*
γ_{ij}	rec	cont	-0.031719	0.019844	
γ_{ij}	rec	elec	-0.018943	0.014114	
γ_{ij}	rec	food	0.011040	0.008037	
γ_{ij}	rec	hlth	0.069118	0.030679	*
γ_{ij}	rec	accom	0.030445	0.034546	
γ_{ij}	rec	insur	-0.004697	0.023054	
γ_{ij}	rec	othr	0.006537	0.016216	
γ_{ij}	rec	rec	-0.010235	0.046150	
γ_{ij}	rec	take	0.078093	0.034077	*
γ_{ij}	rec	trans	0.014648	0.013353	
γ_{ij}	rec	air	0.059711	0.015409	***
γ_{ij}	rec	nrg	-0.019179	0.017261	
γ_{ij}	rec	alc	-0.084661	0.024580	***
γ_{ij}	rec	educ	-0.027962	0.025388	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	rec	cloth	-0.089119	0.024481	***
γ_{ij}	rec	mort	-0.016143	0.018631	
γ_{ij}	take	comm	-0.035398	0.012409	**
γ_{ij}	take	cont	0.051446	0.017412	**
γ_{ij}	take	elec	0.045470	0.009997	***
γ_{ij}	take	food	0.001901	0.005205	
γ_{ij}	take	hlth	-0.022764	0.027876	
γ_{ij}	take	accom	-0.044198	0.035036	
γ_{ij}	take	insur	0.008312	0.020337	
γ_{ij}	take	othr	-0.002908	0.011935	
γ_{ij}	take	rec	0.078093	0.034077	*
γ_{ij}	take	take	0.027380	0.042735	
γ_{ij}	take	trans	0.007741	0.009808	
γ_{ij}	take	air	-0.034300	0.012209	**
γ_{ij}	take	nrg	-0.026295	0.013344	*
γ_{ij}	take	alc	-0.023581	0.022157	
γ_{ij}	take	educ	-0.023880	0.021274	
γ_{ij}	take	cloth	-0.019269	0.021391	
γ_{ij}	take	mort	0.012250	0.012659	
γ_{ij}	trans	comm	0.017449	0.006172	**
γ_{ij}	trans	cont	0.006663	0.008259	
γ_{ij}	trans	elec	-0.002562	0.005972	
γ_{ij}	trans	food	-0.003804	0.005649	
γ_{ij}	trans	hlth	0.014280	0.009587	
γ_{ij}	trans	accom	-0.054926	0.020356	**
γ_{ij}	trans	insur	-0.002491	0.009045	
γ_{ij}	trans	othr	-0.019718	0.008513	*
γ_{ij}	trans	rec	0.014648	0.013353	
γ_{ij}	trans	take	0.007741	0.009808	
γ_{ij}	trans	trans	0.073555	0.009248	***
γ_{ij}	trans	air	-0.002142	0.007083	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	trans	nrg	0.006498	0.005552	
γ_{ij}	trans	alc	-0.029013	0.008272	***
γ_{ij}	trans	educ	0.009631	0.007317	
γ_{ij}	trans	cloth	-0.022500	0.008686	**
γ_{ij}	trans	mort	-0.013308	0.010454	
γ_{ij}	air	comm	-0.025679	0.006624	***
γ_{ij}	air	cont	0.023588	0.009350	*
γ_{ij}	air	elec	0.005792	0.006536	
γ_{ij}	air	food	-0.004086	0.005155	
γ_{ij}	air	hlth	-0.026500	0.011328	*
γ_{ij}	air	accom	0.044377	0.023657	
γ_{ij}	air	insur	-0.005986	0.010373	
γ_{ij}	air	othr	-0.025995	0.009073	**
γ_{ij}	air	rec	0.059711	0.015409	***
γ_{ij}	air	take	-0.034300	0.012209	**
γ_{ij}	air	trans	-0.002142	0.007083	
γ_{ij}	air	air	-0.000432	0.010471	
γ_{ij}	air	nrg	-0.001700	0.006600	
γ_{ij}	air	alc	0.036457	0.009919	***
γ_{ij}	air	educ	-0.035135	0.009506	***
γ_{ij}	air	cloth	-0.024327	0.010724	*
γ_{ij}	air	mort	0.016356	0.009538	
γ_{ij}	nrg	comm	0.014103	0.006779	*
γ_{ij}	nrg	cont	-0.008799	0.009109	
γ_{ij}	nrg	elec	-0.000026	0.004585	
γ_{ij}	nrg	food	0.002427	0.003365	
γ_{ij}	nrg	hlth	0.001647	0.011826	
γ_{ij}	nrg	accom	0.054486	0.026520	*
γ_{ij}	nrg	insur	-0.004391	0.011056	
γ_{ij}	nrg	othr	0.006150	0.008152	
γ_{ij}	nrg	rec	-0.019179	0.017261	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	nrg	take	-0.026295	0.013344	*
γ_{ij}	nrg	trans	0.006498	0.005552	
γ_{ij}	nrg	air	-0.001700	0.006600	
γ_{ij}	nrg	nrg	0.003872	0.006564	
γ_{ij}	nrg	alc	-0.030962	0.009727	**
γ_{ij}	nrg	educ	0.008643	0.008759	
γ_{ij}	nrg	cloth	0.008453	0.010586	
γ_{ij}	nrg	mort	-0.014927	0.006895	*
γ_{ij}	alc	comm	0.018311	0.010504	
γ_{ij}	alc	cont	-0.038113	0.013302	**
γ_{ij}	alc	elec	-0.010012	0.008297	
γ_{ij}	alc	food	0.017892	0.005193	***
γ_{ij}	alc	hlth	0.058993	0.018718	**
γ_{ij}	alc	accom	0.048067	0.029572	
γ_{ij}	alc	insur	0.003713	0.017024	
γ_{ij}	alc	othr	-0.008246	0.010515	
γ_{ij}	alc	rec	-0.084661	0.024580	***
γ_{ij}	alc	take	-0.023581	0.022157	
γ_{ij}	alc	trans	-0.029013	0.008272	***
γ_{ij}	alc	air	0.036457	0.009919	***
γ_{ij}	alc	nrg	-0.030962	0.009727	**
γ_{ij}	alc	alc	0.036009	0.021378	
γ_{ij}	alc	educ	-0.028044	0.014962	
γ_{ij}	alc	cloth	0.011727	0.016050	
γ_{ij}	alc	mort	0.021461	0.011590	
γ_{ij}	educ	comm	-0.002985	0.009631	
γ_{ij}	educ	cont	0.024311	0.012283	*
γ_{ij}	educ	elec	0.038049	0.007226	***
γ_{ij}	educ	food	-0.003325	0.004440	
γ_{ij}	educ	hlth	-0.024258	0.019468	
γ_{ij}	educ	accom	-0.052957	0.028012	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	educ	insur	0.027203	0.016308	
γ_{ij}	educ	othr	-0.009970	0.009344	
γ_{ij}	educ	rec	-0.027962	0.025388	
γ_{ij}	educ	take	-0.023880	0.021274	
γ_{ij}	educ	trans	0.009631	0.007317	
γ_{ij}	educ	air	-0.035135	0.009506	***
γ_{ij}	educ	nrg	0.008643	0.008759	
γ_{ij}	educ	alc	-0.028044	0.014962	
γ_{ij}	educ	educ	0.056772	0.020548	**
γ_{ij}	educ	cloth	0.029909	0.015689	
γ_{ij}	educ	mort	0.013996	0.009440	
γ_{ij}	cloth	comm	0.019868	0.010679	
γ_{ij}	cloth	cont	0.008385	0.014830	
γ_{ij}	cloth	elec	-0.007259	0.008920	
γ_{ij}	cloth	food	0.002132	0.005320	
γ_{ij}	cloth	hlth	0.089274	0.021788	***
γ_{ij}	cloth	accom	-0.036237	0.031627	
γ_{ij}	cloth	insur	0.006692	0.017094	
γ_{ij}	cloth	othr	0.006767	0.011362	
γ_{ij}	cloth	rec	-0.089119	0.024481	***
γ_{ij}	cloth	take	-0.019269	0.021391	
γ_{ij}	cloth	trans	-0.022500	0.008686	**
γ_{ij}	cloth	air	-0.024327	0.010724	*
γ_{ij}	cloth	nrg	0.008453	0.010586	
γ_{ij}	cloth	alc	0.011727	0.016050	
γ_{ij}	cloth	educ	0.029909	0.015689	
γ_{ij}	cloth	cloth	-0.000711	0.023873	
γ_{ij}	cloth	mort	0.016217	0.012117	
γ_{ij}	mort	comm	-0.012630	0.009039	
γ_{ij}	mort	cont	0.032104	0.011731	**
γ_{ij}	mort	elec	-0.040776	0.008017	***

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
γ_{ij}	mort	food	-0.001740	0.009476	
γ_{ij}	mort	hlth	0.001400	0.012469	
γ_{ij}	mort	accom	-0.036719	0.031768	
γ_{ij}	mort	insur	0.006447	0.013236	
γ_{ij}	mort	othr	0.002592	0.013150	
γ_{ij}	mort	rec	-0.016143	0.018631	
γ_{ij}	mort	take	0.012250	0.012659	
γ_{ij}	mort	trans	-0.013308	0.010454	
γ_{ij}	mort	air	0.016356	0.009538	
γ_{ij}	mort	nrg	-0.014927	0.006895	*
γ_{ij}	mort	alc	0.021461	0.011590	
γ_{ij}	mort	educ	0.013996	0.009440	
γ_{ij}	mort	cloth	0.016217	0.012117	
γ_{ij}	mort	mort	0.013419	0.018724	
δ_{is}	comm	comm	0.006065	0.001639	***
δ_{is}	comm	cont	-0.000050	0.000098	
δ_{is}	comm	elec	0.000002	0.000001	*
δ_{is}	comm	food	-0.007429	0.001860	***
δ_{is}	comm	hlth	-0.001195	0.001269	
δ_{is}	cont	accom	-0.010490	0.002552	***
δ_{is}	cont	insur	-0.000029	0.000153	
δ_{is}	cont	othr	0.000005	0.000001	**
δ_{is}	cont	rec	0.000515	0.002894	
δ_{is}	cont	take	0.001542	0.001972	
δ_{is}	elec	trans	0.022535	0.001598	***
δ_{is}	elec	air	0.000193	0.000095	*
δ_{is}	elec	nrg	-0.000001	0.000001	
δ_{is}	elec	alc	0.017048	0.001812	***
δ_{is}	elec	educ	-0.010520	0.001237	***
δ_{is}	food	cloth	0.134743	0.004035	***
δ_{is}	food	mort	0.000955	0.000242	***

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
δ_{is}	food	comm	-0.000001	0.000002	
δ_{is}	food	cont	-0.004415	0.004580	
δ_{is}	food	elec	0.022637	0.003117	***
δ_{is}	hlth	food	-0.007714	0.002294	***
δ_{is}	hlth	hlth	-0.000264	0.000137	
δ_{is}	hlth	accom	0.000009	0.000001	***
δ_{is}	hlth	insur	0.008471	0.002601	**
δ_{is}	hlth	othr	0.002350	0.001773	
δ_{is}	accom	rec	-0.078007	0.007846	***
δ_{is}	accom	take	-0.002148	0.000470	***
δ_{is}	accom	trans	-0.000017	0.000005	***
δ_{is}	accom	air	0.113497	0.008902	***
δ_{is}	accom	nrg	0.034652	0.006061	***
δ_{is}	insur	alc	-0.012259	0.002294	***
δ_{is}	insur	educ	0.001003	0.000137	***
δ_{is}	insur	cloth	0.000001	0.000001	
δ_{is}	insur	mort	-0.021646	0.002601	***
δ_{is}	insur	comm	-0.018023	0.001772	***
δ_{is}	othr	cont	-0.028064	0.003214	***
δ_{is}	othr	elec	0.000239	0.000193	
δ_{is}	othr	food	-0.000002	0.000002	
δ_{is}	othr	hlth	-0.019870	0.003648	***
δ_{is}	othr	accom	-0.022888	0.002484	***
δ_{is}	rec	insur	-0.030620	0.003747	***
δ_{is}	rec	othr	-0.000354	0.000224	
δ_{is}	rec	rec	0.000014	0.000002	***
δ_{is}	rec	take	-0.006433	0.004249	
δ_{is}	rec	trans	-0.010178	0.002895	***
δ_{is}	take	air	-0.005938	0.002230	**
δ_{is}	take	nrg	-0.001328	0.000133	***
δ_{is}	take	alc	0.000013	0.000001	***

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
δ_{is}	take	educ	-0.013194	0.002529	***
δ_{is}	take	cloth	-0.011645	0.001723	***
δ_{is}	trans	mort	0.036616	0.003093	***
δ_{is}	trans	comm	0.001179	0.000185	***
δ_{is}	trans	cont	-0.000009	0.000002	***
δ_{is}	trans	elec	-0.027722	0.003511	***
δ_{is}	trans	food	0.008579	0.002391	***
δ_{is}	air	hlth	-0.018836	0.002305	***
δ_{is}	air	accom	0.000013	0.000138	
δ_{is}	air	insur	0.000001	0.000001	
δ_{is}	air	othr	-0.001011	0.002615	
δ_{is}	air	rec	-0.003159	0.001782	
δ_{is}	nrg	take	0.002016	0.000696	**
δ_{is}	nrg	trans	0.000147	0.000041	***
δ_{is}	nrg	air	-0.000001	0.000000	*
δ_{is}	nrg	nrg	0.002397	0.000784	**
δ_{is}	nrg	alc	-0.002272	0.000545	***
δ_{is}	alc	educ	-0.012246	0.002385	***
δ_{is}	alc	cloth	0.000726	0.000143	***
δ_{is}	alc	mort	-0.000007	0.000001	***
δ_{is}	alc	comm	0.001179	0.002705	
δ_{is}	alc	cont	-0.007094	0.001843	***
δ_{is}	educ	elec	0.020667	0.001791	***
δ_{is}	educ	food	-0.000673	0.000107	***
δ_{is}	educ	hlth	0.000004	0.000001	***
δ_{is}	educ	accom	-0.004075	0.002031	*
δ_{is}	educ	insur	0.005380	0.001386	***
δ_{is}	cloth	othr	0.000438	0.002340	
δ_{is}	cloth	rec	-0.000482	0.000140	***
δ_{is}	cloth	take	0.000006	0.000001	***
δ_{is}	cloth	trans	0.000447	0.002652	

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Coefficients of AIDS model, continued from previous page

Coefficient	Variable i	Variable j/s	Estimate	Standard error	Significance
δ_{is}	cloth	air	-0.000404	0.001808	
δ_{is}	mort	nrg	-0.018905	0.004726	***
δ_{is}	mort	alc	0.000872	0.000283	**
δ_{is}	mort	educ	-0.000017	0.000003	***
δ_{is}	mort	cloth	-0.037760	0.005368	***
δ_{is}	mort	mort	0.012238	0.003656	***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C.3 Empirical distributions for demand elasticities

This subsection presents summaries of the variance in individual household product-specific uncompensated own-price demand elasticities under the AIDS model and QUAIDS model. The summaries are based on a random sample of 3,000 households observed in our overall data set. The variance in household elasticities is presented by way of empirical kernel densities.[1]

C.4 Elasticities

[1]Produced using a default bandwidth in R which is ”0.9 times the minimum of the standard deviation and the interquartile range divided by 1.34 times the sample size to the negative one-fifth power” `https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/bandwidth`.

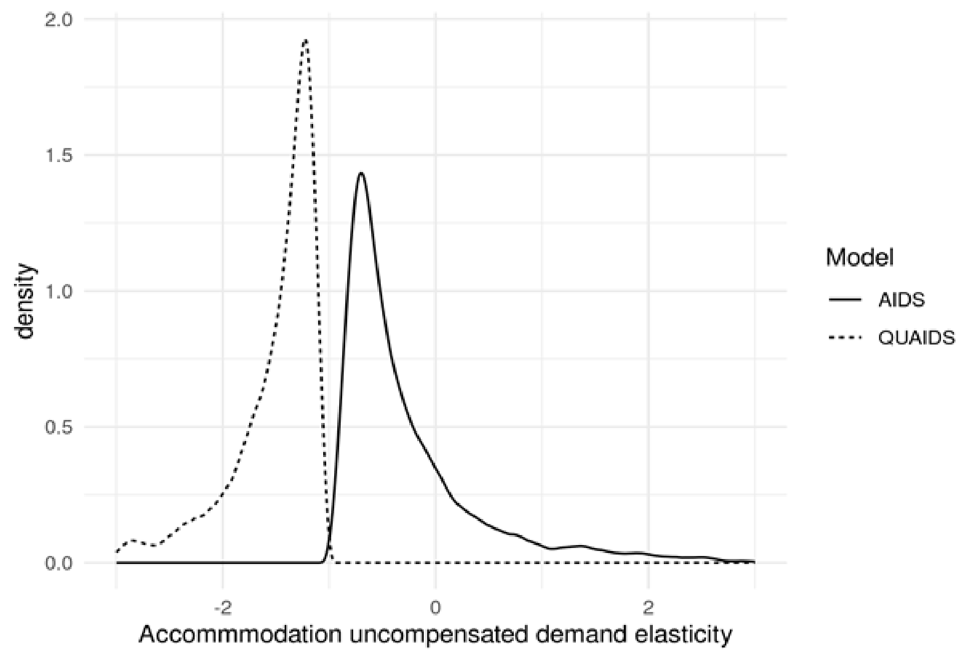

Figure C.1: Accommodation, own-price uncompensated elasticities empirical densities.

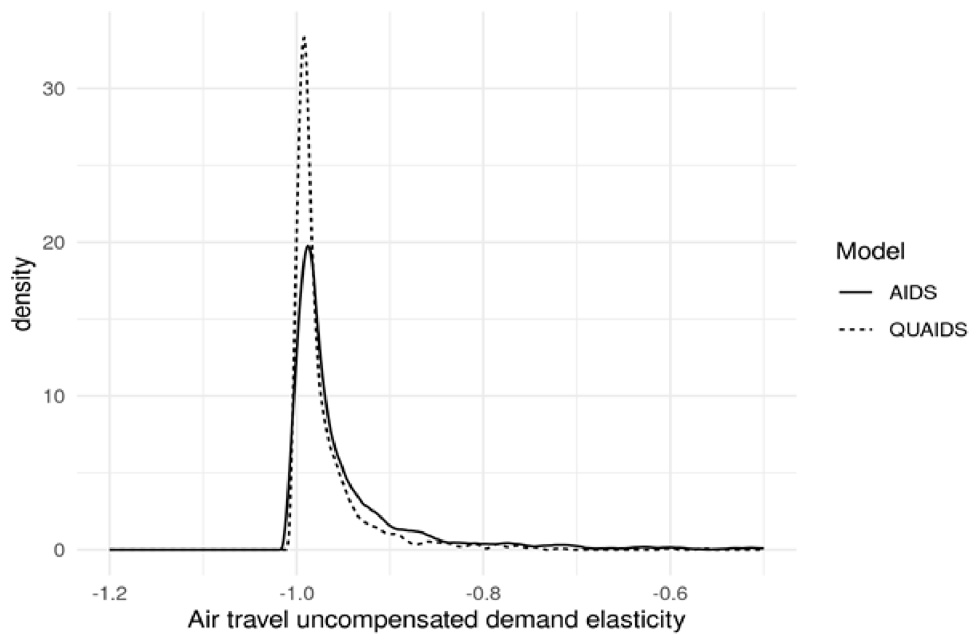

Figure C.2: Air transport, own-price uncompensated elasticities empirical densities.

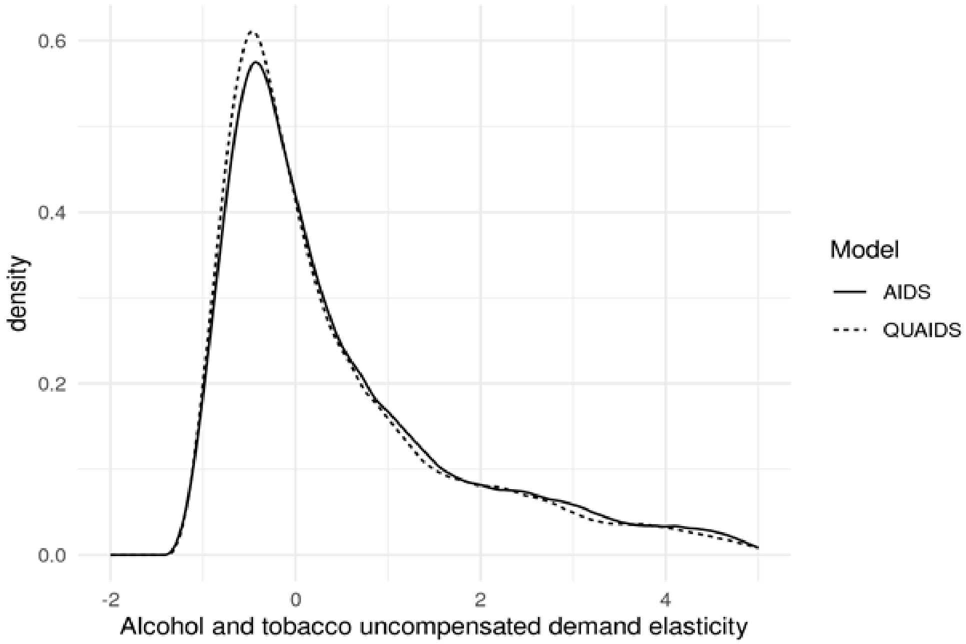

Figure C.3: Alcohol and tobacco, own-price uncompensated elasticities empirical densities.

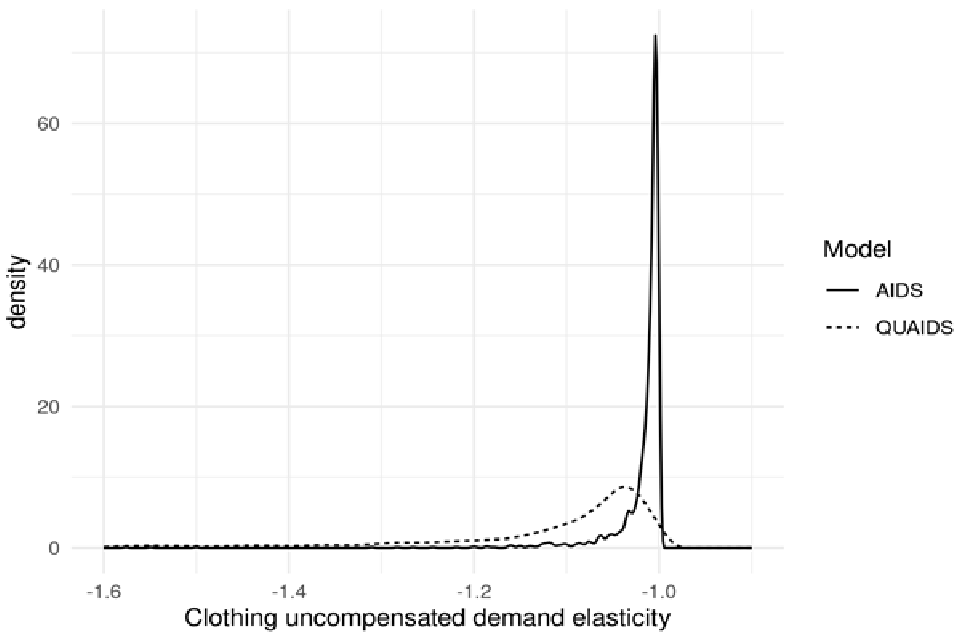

Figure C.4: Clothing, own-price uncompensated elasticities empirical densities.

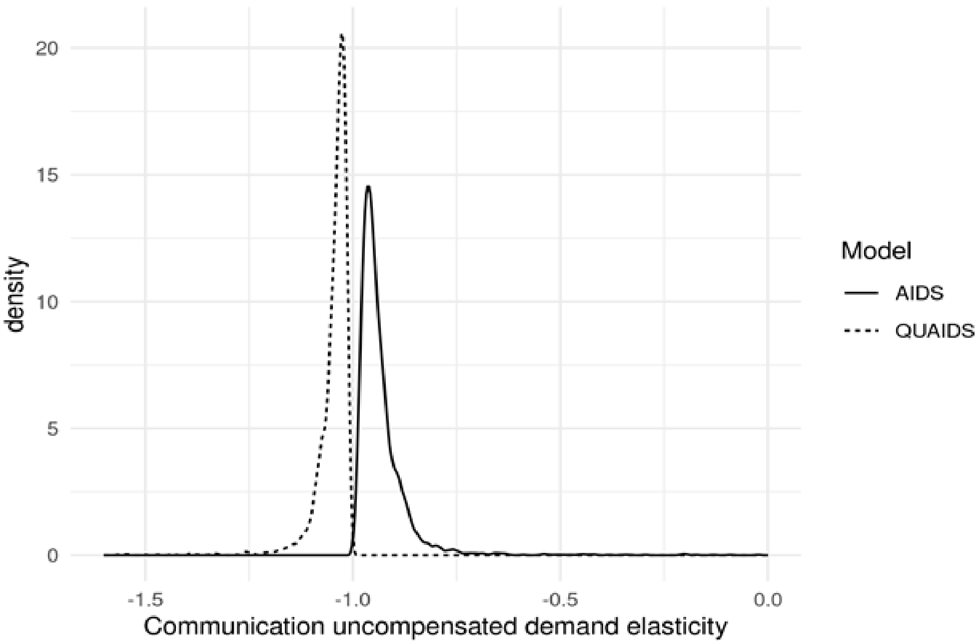

Figure C.5: Communications, own-price uncompensated elasticities empirical densities.

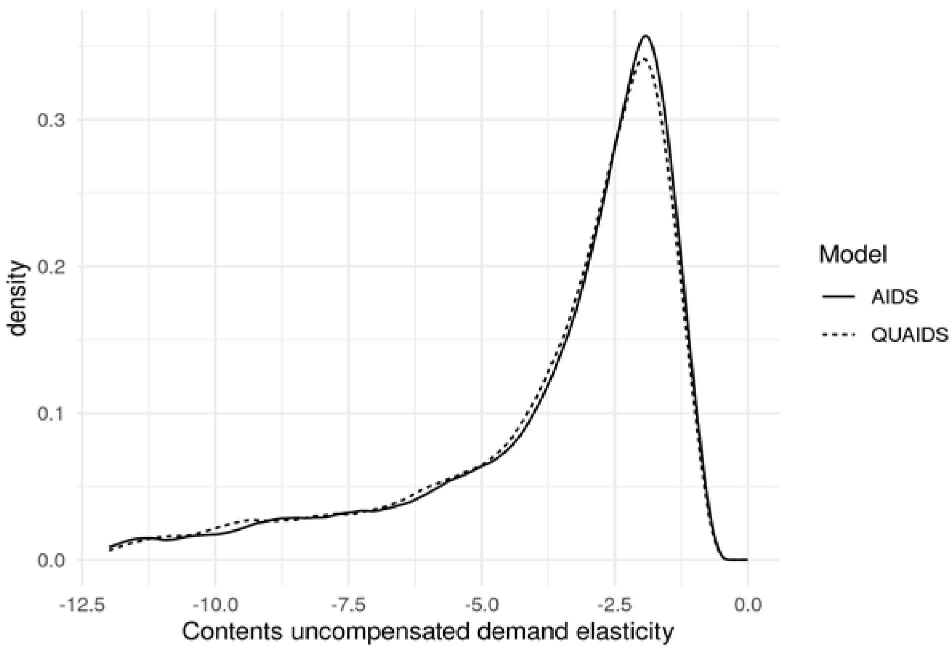

Figure C.6: Household contents, own-price uncompensated elasticities empirical densities.

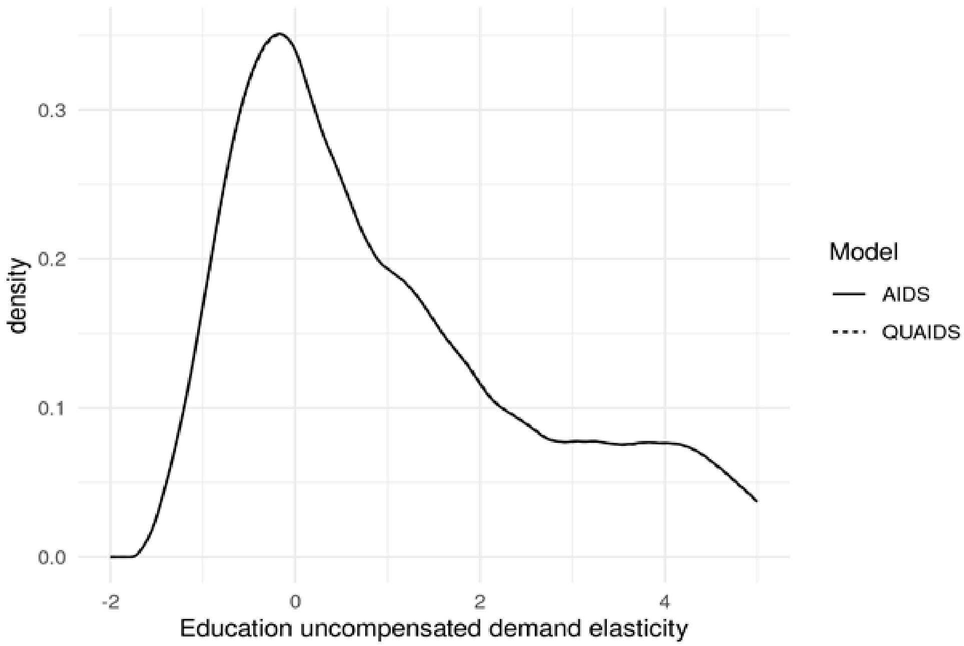

Figure C.7: Education, own-price uncompensated elasticities empirical densities.

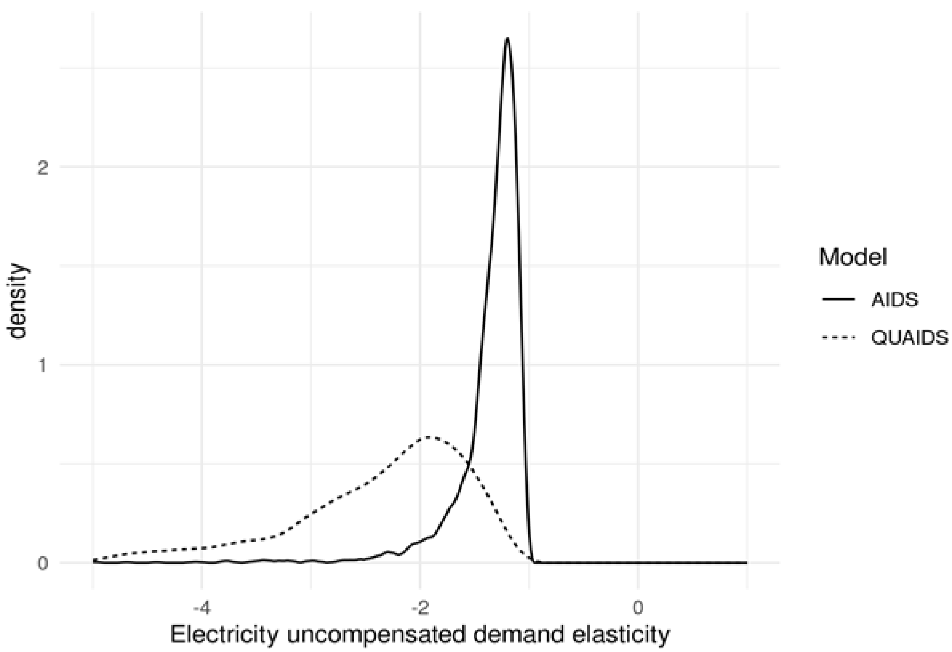

Figure C.8: Electricity, own-price uncompensated elasticities empirical densities.

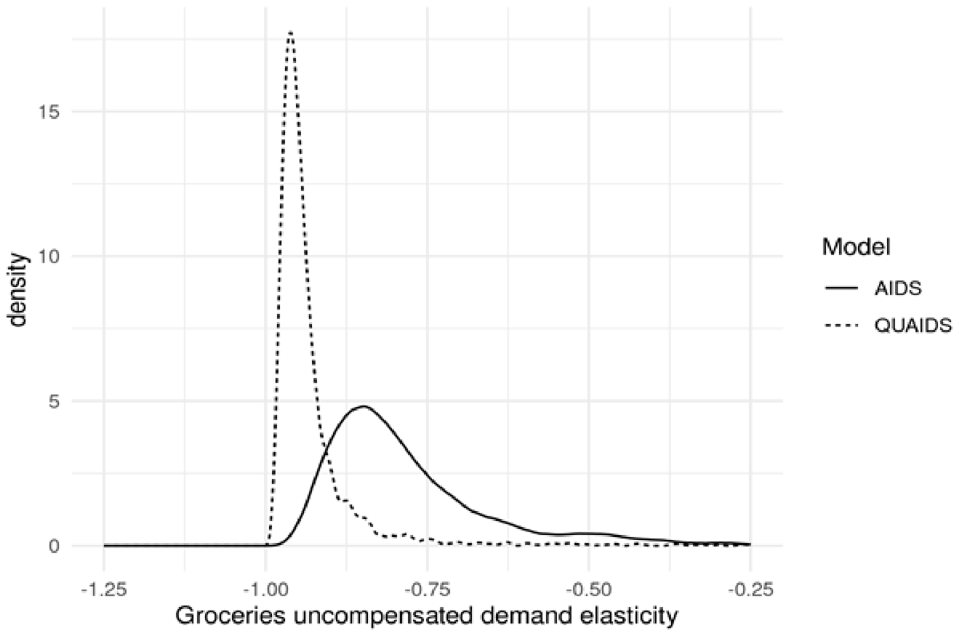

Figure C.9: Groceries, own-price uncompensated elasticities empirical densities.

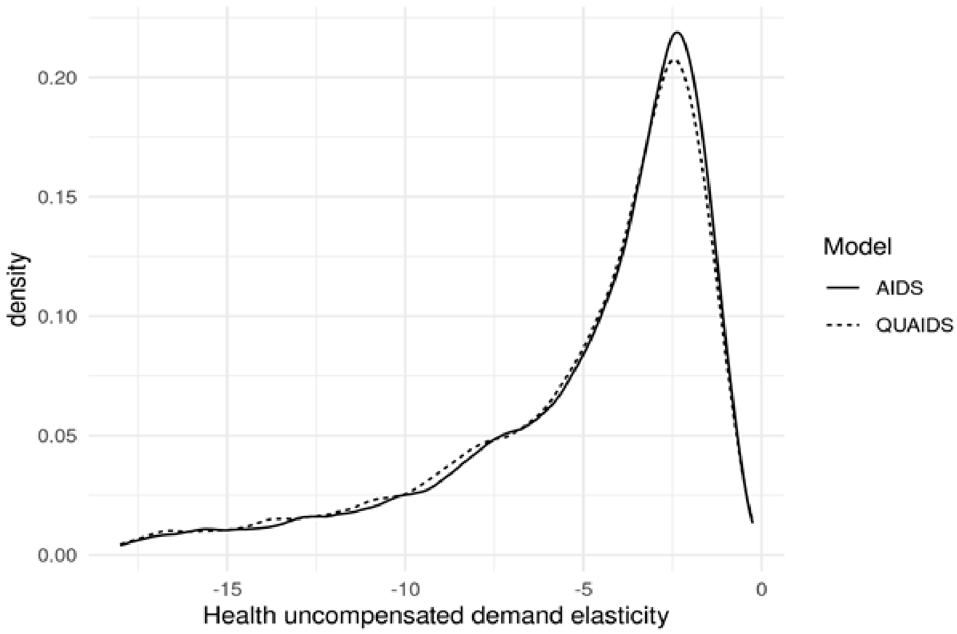

Figure C.10: Health, own-price uncompensated elasticities empirical densities.

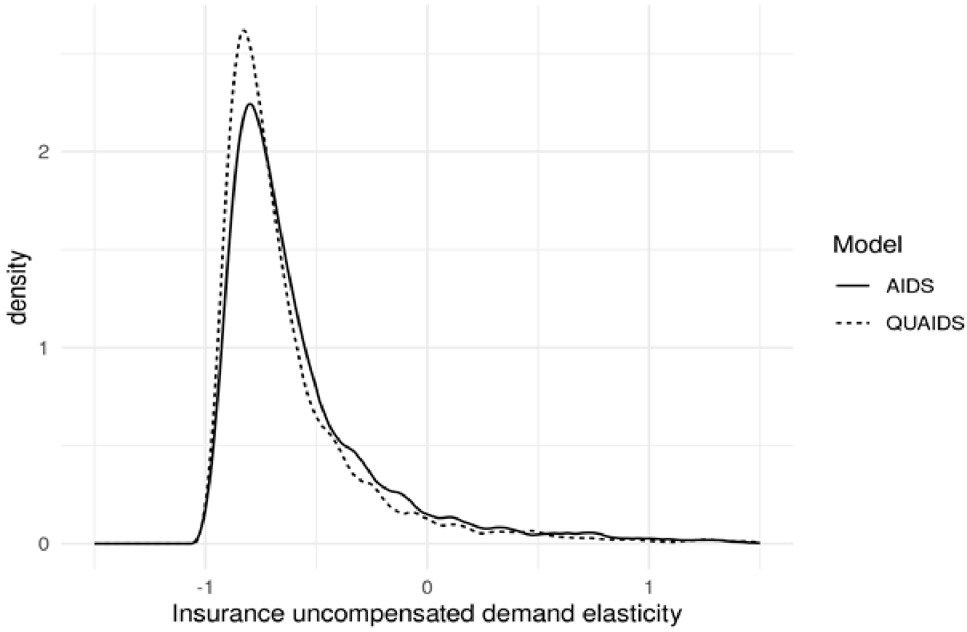

Figure C.11: Insurance, own-price uncompensated elasticities empirical densities.

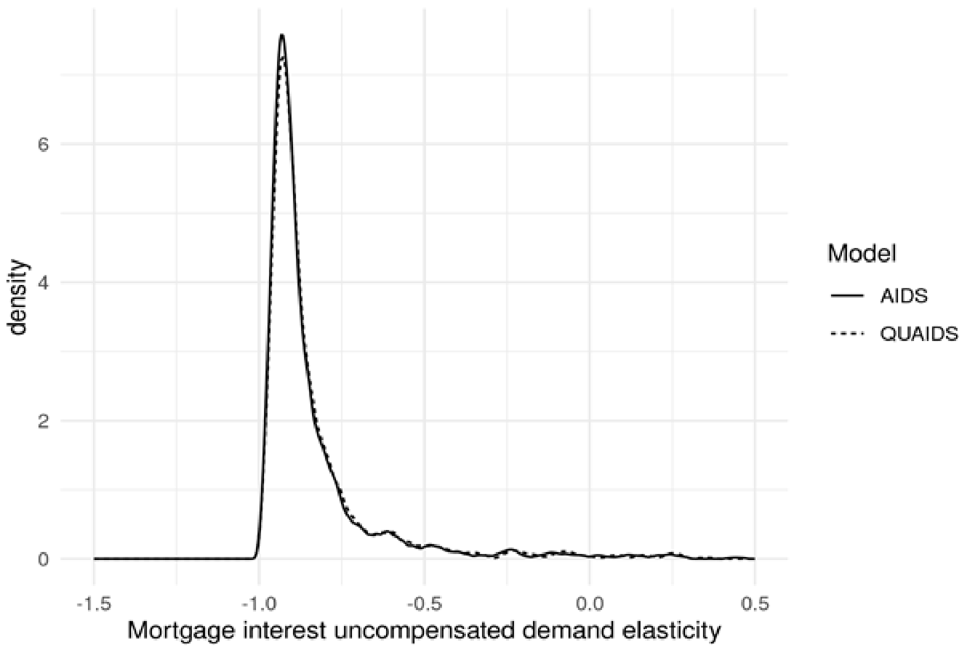

Figure C.12: Mortgage interest, own-price uncompensated elasticities empirical densities.

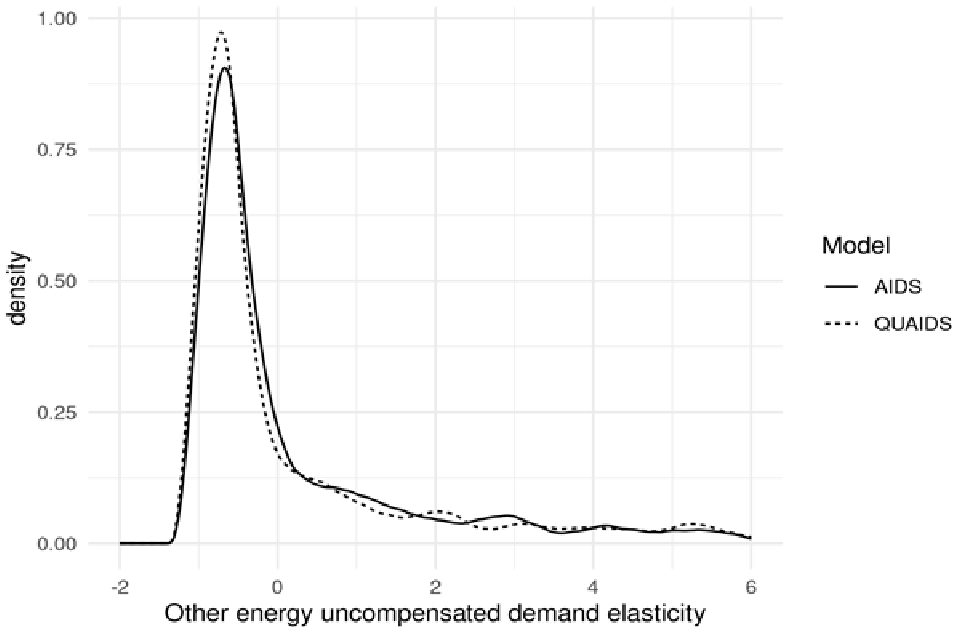

Figure C.13: Energy excluding electricity, own-price uncompensated elasticities empirical densities.

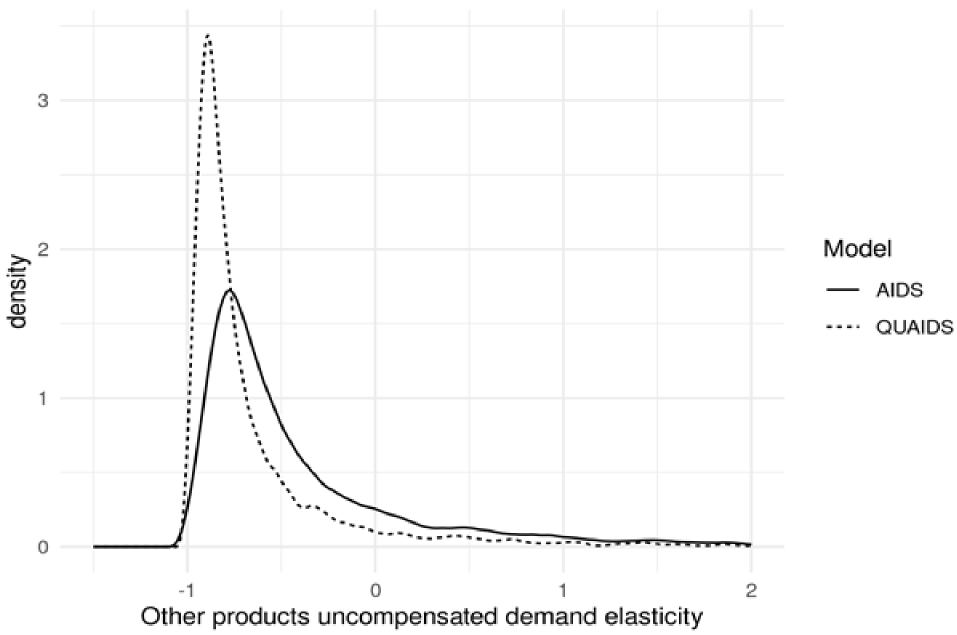

Figure C.14: Miscellaneous, own-price uncompensated elasticities empirical densities.

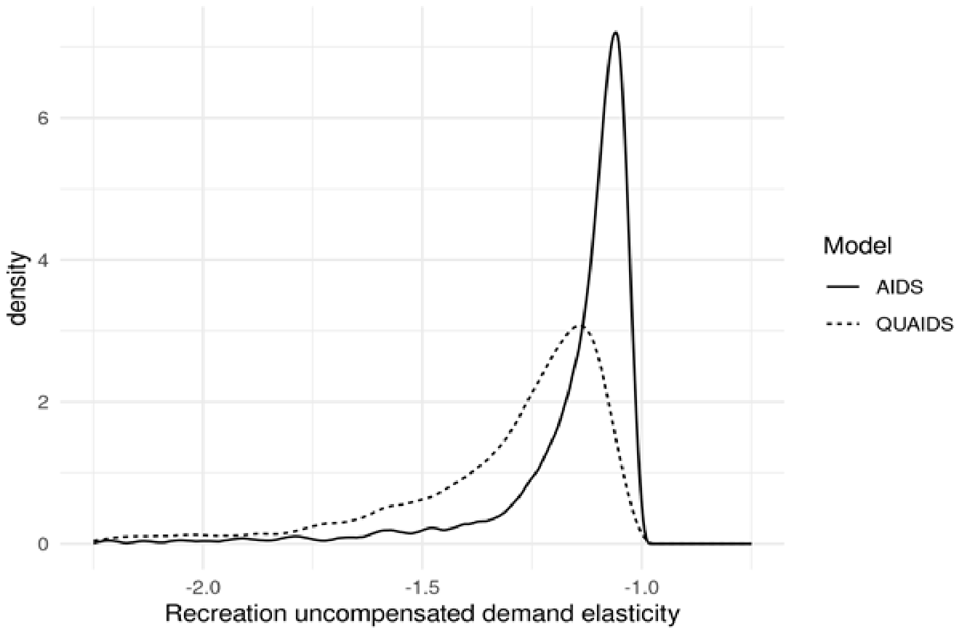

Figure C.15: Recreation, own-price uncompensated elasticities empirical densities.

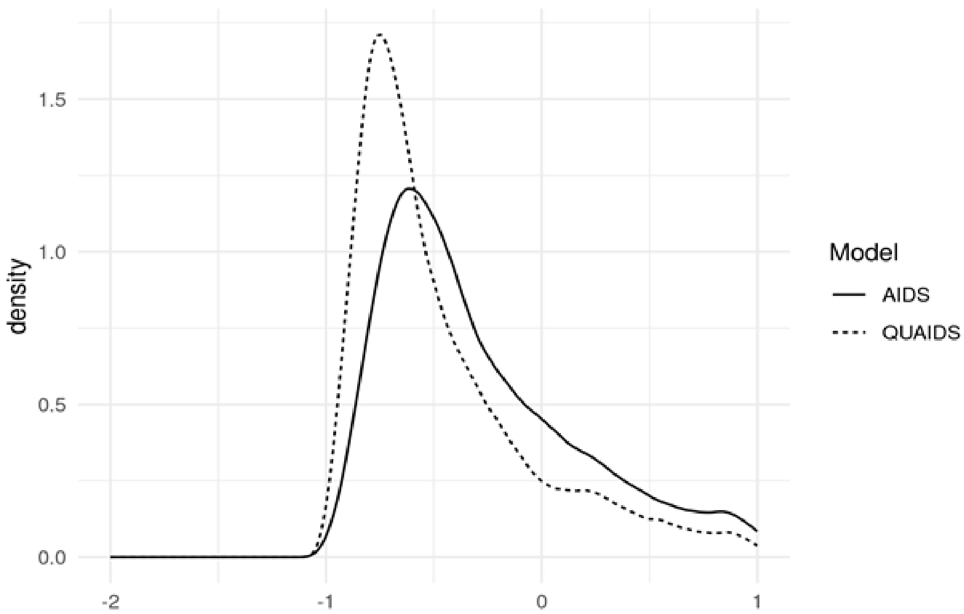

Figure C.16: Takeaways and eating out, own-price uncompensated elasticities empirical densities.

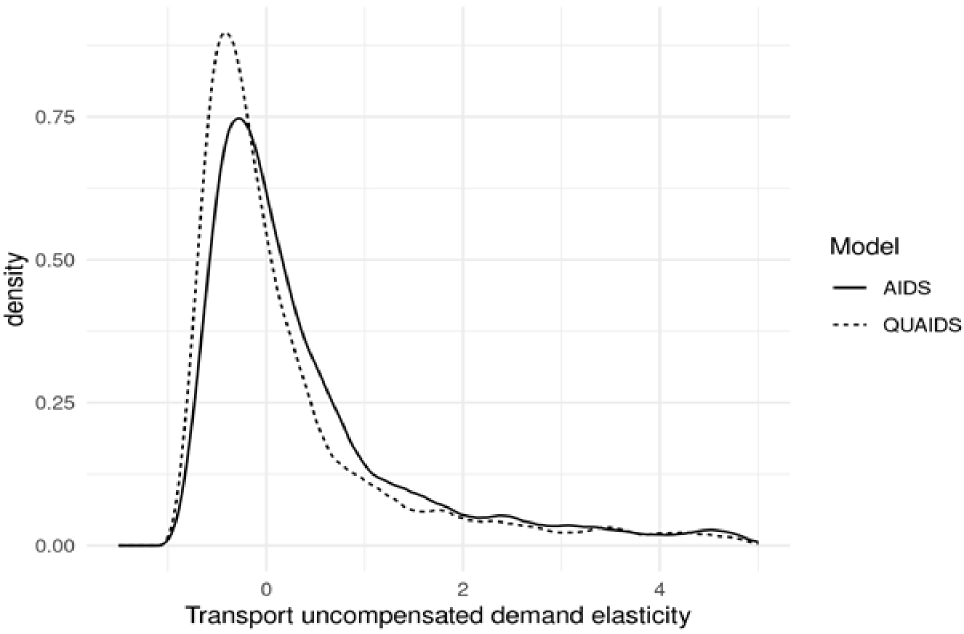

Figure C.17: Transport, own-price uncompensated elasticities empirical densities.

Table C.5: QUAIDS model compensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-1.15**	**0.23**	**0.33**	-0.09	**-0.20**	**0.32**	-0.04	**-0.28**	**-0.36**	0.04	0.01	**0.13**	**0.43**	**-0.23**	**0.23**	**0.40**	0.01
air	3.17	**-0.94**	**2.00**	**-1.26**	**-1.36**	**1.39**	**-1.80**	**-1.95**	0.45	-0.06	**-1.40**	-0.26	**-1.33**	**1.13**	**-0.09**	**3.45**	-0.09
alc	2.74	**1.28**	**0.23**	**0.37**	**0.82**	**-1.48**	**-1.01**	**-0.88**	0.12	**0.74**	**1.99**	**0.14**	-0.44	**0.94**	**-1.07**	**-3.17**	**-1.18**
cloth	-0.59	**-0.89**	**0.41**	**-1.05**	**0.89**	0.29	**-0.80**	**1.23**	0.11	**0.22**	**3.39**	**0.33**	0.23	**0.80**	**0.35**	**-3.41**	**-0.93**
comm	-1.23	**-0.66**	**0.57**	**0.57**	**-1.01**	**0.32**	**-0.82**	**-0.07**	**0.59**	**0.24**	**-0.60**	-0.15	0.20	**-0.40**	**0.36**	**0.98**	**0.64**
cont	1.83	**0.59**	**-0.98**	**0.17**	**0.33**	**-2.45**	**1.16**	**0.62**	-0.49	**0.47**	**-0.87**	**0.69**	**-0.80**	**0.95**	**-0.18**	**-0.77**	0.07
take	-0.08	**-0.81**	**-0.68**	**-0.51**	**-0.74**	**1.19**	**-0.52**	**-0.48**	**1.57**	**0.17**	**-0.70**	**0.30**	-0.18	**0.52**	**-0.57**	**1.88**	0.07
educ	-5.77	**-3.33**	**-2.32**	**2.98**	-0.24	**2.44**	**-1.87**	**4.36**	**3.22**	-0.10	**-2.04**	**2.48**	-0.56	**1.12**	**0.73**	-2.41	1.26
elec	-1.71	0.13	0.05	0.02	**0.45**	**-0.45**	**1.24**	**0.68**	**-1.95**	**0.30**	**0.68**	0.02	0.61	**-1.05**	-0.05	-0.03	0.41
food	0.02	**-0.04**	**0.13**	**0.01**	**0.07**	**0.10**	0.01	-0.01	0.11	**-0.87**	**-0.07**	0.01	-0.01	0.01	**0.02**	0.08	0.01
hlth	0.19	**-0.95**	**2.05**	**3.23**	**-0.83**	**-1.34**	**-1.06**	**-0.80**	**1.31**	**-0.27**	**-3.78**	**-1.59**	**0.90**	0.28	**0.13**	**2.48**	0.37
insur	0.63	**-0.11**	0.08	**0.15**	-0.09	**0.54**	**0.22**	**0.51**	0.06	**0.11**	**-0.83**	**-0.70**	**-0.49**	0.23	**-0.09**	-0.05	-0.03
othr	1.51	**-0.36**	**-0.17**	**0.08**	**0.15**	**-0.47**	**-0.10**	-0.08	**0.49**	0.10	**0.35**	**-0.36**	**-0.74**	0.22	**0.11**	0.07	**-0.37**
mort	-0.56	**0.36**	**0.43**	**0.35**	**-0.24**	**0.68**	**0.32**	**0.25**	**-0.79**	0.02	0.08	**0.19**	0.17	**-0.65**	**-0.28**	-0.14	-0.20
nrg	8.47	-0.27	**-4.83**	**1.47**	**2.28**	-1.27	**-3.83**	**1.27**	-0.36	**0.56**	0.57	-0.80	1.26	**-2.52**	**-0.50**	-2.90	1.30
rec	1.11	**0.67**	**-0.95**	**-0.96**	**0.45**	**-0.35**	**0.84**	**-0.27**	0.04	**0.24**	**0.74**	**-0.01**	0.05	0.00	**-0.19**	**-1.09**	0.12
trans	0.03	**-0.05**	**-0.45**	**-0.34**	**0.34**	0.02	0.01	**0.18**	0.29	0.04	**0.12**	**-0.04**	**-0.39**	-0.07	**0.11**	0.08	**-0.12**

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.6: AIDS model compensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	-0.40	0.20	0.24	-0.15	-0.10	0.21	-0.17	-0.23	-0.02	0.05	-0.09	0.07	0.23	-0.13	**0.25**	0.20	-0.16
air	2.48	-0.92	**2.05**	**-1.26**	**-1.46**	**1.40**	**-1.78**	**-1.93**	0.23	-0.34	**-1.40**	-0.25	**-1.24**	**1.06**	-0.09	**3.55**	-0.12
alc	1.92	**1.34**	0.32	0.45	0.69	**-1.32**	-0.79	-0.99	-0.33	**0.75**	**2.15**	0.19	-0.21	**0.84**	**-1.10**	**-2.92**	**-0.97**
cloth	-1.28	**-0.88**	0.49	-0.97	0.76	0.39	-0.66	1.16	-0.30	0.09	**3.49**	0.33	0.40	0.73	0.33	**-3.26**	**-0.83**
comm	-0.59	**-0.68**	0.49	0.51	**-0.94**	0.25	**-0.90**	-0.06	**0.84**	**0.35**	**-0.66**	-0.15	0.06	-0.32	**0.37**	**0.87**	**0.56**
cont	1.11	**0.61**	**-0.88**	0.24	0.24	**-2.35**	**1.29**	**0.59**	**-0.82**	**0.42**	**-0.77**	**0.70**	**-0.61**	**0.85**	-0.21	-0.62	0.21
take	-0.93	**-0.79**	-0.54	-0.42	**-0.86**	**1.32**	-0.26	-0.57	**1.11**	0.09	-0.51	0.27	0.05	0.39	-0.64	**2.06**	0.23
educ	-4.74	**-3.29**	-2.61	2.83	-0.24	**2.32**	-2.21	**4.34**	**3.63**	-0.15	-2.25	2.61	-0.87	1.36	0.82	-2.54	0.98
elec	-0.09	0.08	-0.18	-0.15	**0.65**	**-0.69**	**0.90**	**0.77**	**-1.19**	**0.38**	**0.44**	0.02	0.18	**-0.82**	0.01	-0.38	0.07
food	0.07	-0.04	**0.14**	0.02	**0.09**	**0.12**	0.02	-0.01	**0.13**	**-0.74**	-0.06	0.03	0.01	0.00	0.02	0.11	**0.08**
hlth	-0.73	**-0.93**	**2.20**	**3.33**	**-0.94**	**-1.19**	-0.77	-0.88	**0.82**	-0.31	**-3.58**	**-1.63**	**1.15**	0.13	0.07	**2.68**	0.58
insur	0.31	-0.08	0.10	0.16	-0.11	**0.56**	0.21	0.53	0.02	0.09	**-0.84**	-0.66	-0.43	0.19	-0.08	0.02	0.02
othr	0.75	**-0.32**	-0.09	0.15	0.03	**-0.37**	0.03	-0.13	0.13	0.02	**0.45**	-0.32	**-0.56**	0.13	0.09	0.25	-0.24
mort	-0.55	**0.36**	0.44	0.36	-0.23	**0.67**	0.30	0.27	**-0.77**	0.01	0.07	0.19	0.17	-0.65	**-0.28**	-0.15	-0.21
nrg	**9.08**	-0.27	**-4.99**	1.39	**2.33**	-1.39	-4.23	1.41	0.06	0.57	0.29	-0.66	1.05	**-2.38**	-0.37	-3.03	1.14
rec	0.48	**0.70**	**-0.89**	**-0.92**	**0.37**	-0.28	**0.92**	-0.29	-0.21	0.17	**0.79**	0.01	0.19	-0.08	-0.20	-0.96	0.20
trans	-0.47	-0.03	**-0.36**	**-0.29**	**0.29**	0.12	0.13	0.14	0.05	**0.15**	0.21	0.01	-0.22	-0.15	0.09	0.25	0.07

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.7: QUAIDS model, sample 2013-2019, uncompensated price elasticities

Quantity:	Price: accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-1.62**	**0.26**	**0.58**	**-0.30**	**-0.29**	0.09	**-0.16**	**-0.10**	**-0.24**	-0.02	0.11	**-0.23**	**0.39**	**-0.55**	**0.27**	**0.78**	0.04
air	2.87	0.01	**1.40**	-0.13	**-1.04**	**1.02**	**-1.62**	**-1.59**	0.93	-0.23	**-0.76**	-0.22	**-1.82**	**0.51**	**-0.34**	-0.21	0.21
alc	5.26	**1.16**	-0.05	**-0.84**	**1.19**	**-1.38**	**-3.20**	**-0.53**	-0.49	**0.27**	**1.95**	**-0.43**	-0.62	0.41	**-1.21**	**-1.35**	**-1.13**
cloth	-2.95	-0.11	**-0.91**	**-1.03**	**1.19**	**2.45**	**1.53**	**-0.77**	0.77	0.20	**5.78**	**1.07**	**1.16**	-0.07	**1.29**	**-7.64**	**-2.96**
comm	-1.77	**-0.58**	**0.81**	**0.75**	**-1.18**	**0.42**	**-1.91**	**0.47**	0.06	0.07	**-0.56**	0.20	0.17	**-0.93**	**0.31**	**2.14**	**0.54**
cont	0.53	**0.56**	**-0.93**	**1.52**	**0.42**	**-2.72**	**2.25**	**0.39**	0.23	**0.43**	**-1.45**	**0.36**	-0.42	-0.04	**-0.47**	**-1.49**	-0.17
take	-0.91	**-0.82**	**-1.96**	**0.87**	**-1.72**	**2.04**	**0.75**	**-0.65**	**1.16**	**-0.33**	**-3.43**	**1.67**	**-0.61**	**2.49**	**-0.28**	**0.68**	0.05
educ	-2.31	**-3.26**	**-1.32**	**-1.77**	**1.71**	**1.44**	**-2.63**	**2.68**	**3.53**	0.29	**1.32**	**1.58**	-0.78	**1.80**	**0.73**	**-3.78**	-0.24
elec	-1.11	**0.39**	-0.25	**0.37**	**0.05**	0.17	**0.97**	**0.73**	**-2.71**	0.25	**0.51**	**0.64**	0.15	**0.56**	**-0.09**	**-1.97**	0.33
food	-0.03	**-0.04**	**0.05**	**0.03**	0.02	**0.12**	**-0.10**	0.02	0.09	**-1.01**	**-0.08**	-0.02	0.02	0.00	**0.02**	**-0.11**	0.02
hlth	0.90	**-0.58**	**1.82**	**5.01**	**-0.76**	**-2.01**	**-5.24**	**0.50**	**0.94**	**-0.44**	**-3.73**	0.10	0.56	**-0.80**	**-0.78**	**3.04**	**0.49**
insur	-1.00	**-0.08**	**-0.20**	**0.46**	0.14	**0.25**	**1.28**	**0.30**	**0.59**	-0.04	0.05	**-0.37**	**-0.87**	**-0.71**	**-0.15**	-0.10	**-0.54**
othr	1.36	**-0.57**	**-0.24**	**0.41**	0.09	**-0.24**	**-0.38**	**-0.12**	0.11	0.03	**0.23**	**-0.71**	-0.09	-0.07	**0.07**	**-0.50**	**-0.39**
mort	-2.56	**0.22**	0.18	-0.05	**-0.72**	-0.07	**2.07**	**0.39**	**0.62**	-0.14	**-0.48**	**-0.83**	-0.15	**-1.41**	**0.02**	**0.99**	**0.44**
nrg	11.45	**-1.31**	**-5.64**	**5.56**	**2.12**	**-3.28**	-2.11	**1.37**	-0.86	0.50	**-3.89**	**-1.49**	0.84	0.21	**-0.09**	**-6.90**	2.52
rec	2.14	**-0.05**	**-0.41**	**-2.15**	**0.96**	**-0.67**	**0.34**	**-0.46**	**-1.17**	**-0.19**	**0.99**	**-0.07**	**-0.40**	**0.61**	**-0.45**	**0.37**	**-0.38**
trans	0.13	**0.06**	**-0.41**	**-1.00**	**0.29**	**-0.09**	0.03	-0.04	0.23	0.04	**0.19**	**-0.42**	**-0.38**	**0.38**	**0.20**	**-0.45**	**0.23**

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.8: QUAIDS model, sample 2013-2019, compensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-1.44**	**0.28**	**0.60**	**-0.28**	**-0.26**	0.12	-0.13	**-0.09**	**-0.20**	0.10	**0.13**	**-0.19**	**0.45**	**-0.51**	**0.28**	**0.85**	0.09
air	3.37	0.05	**1.46**	-0.08	**-0.96**	**1.10**	**-1.53**	**-1.57**	1.04	0.07	**-0.70**	-0.10	**-1.67**	**0.62**	**-0.33**	-0.03	0.36
alc	5.54	**1.18**	-0.02	**-0.81**	**1.23**	**-1.34**	**-3.15**	**-0.52**	-0.43	**0.44**	**1.98**	**-0.36**	-0.54	0.47	**-1.20**	**-1.25**	**-1.04**
cloth	-2.58	-0.08	**-0.87**	**-0.99**	**1.25**	**2.51**	**1.59**	**-0.75**	0.85	**0.43**	**5.83**	**1.15**	**1.26**	0.01	**1.30**	**-7.51**	**-2.85**
comm	-1.65	**-0.57**	**0.82**	**0.76**	**-1.16**	**0.44**	**-1.89**	**0.47**	0.09	0.15	**-0.54**	0.23	0.20	**-0.90**	**0.31**	**2.18**	**0.58**
cont	0.84	**0.59**	**-0.90**	**1.56**	**0.47**	**-2.67**	**2.30**	**0.40**	0.29	**0.63**	**-1.41**	**0.44**	-0.33	0.03	**-0.47**	**-1.37**	-0.07
take	-0.59	**-0.79**	**-1.92**	**0.90**	**-1.67**	**2.10**	**0.81**	**-0.63**	**1.23**	**-0.13**	**-3.39**	**1.74**	**-0.52**	**2.55**	**-0.27**	**0.80**	0.15
educ	-2.10	**-3.24**	**-1.30**	**-1.75**	**1.75**	**1.47**	**-2.59**	**2.69**	**3.58**	0.41	**1.35**	**1.63**	-0.72	**1.84**	**0.74**	**-3.70**	-0.18
elec	-1.02	**0.40**	-0.24	**0.38**	**0.06**	0.19	**0.99**	**0.73**	**-2.69**	0.31	**0.52**	**0.66**	0.18	**0.58**	**-0.09**	**-1.94**	0.36
food	0.11	-0.02	**0.06**	**0.05**	0.04	**0.14**	**-0.07**	0.03	0.12	**-0.93**	**-0.07**	**0.02**	0.06	0.03	**0.02**	-0.06	0.06
hlth	1.22	**-0.55**	**1.85**	**5.04**	**-0.71**	**-1.96**	**-5.18**	**0.51**	**1.01**	**-0.24**	**-3.70**	**0.18**	0.66	**-0.73**	**-0.77**	**3.16**	**0.59**
insur	-0.73	**-0.06**	**-0.17**	**0.49**	**0.18**	**0.30**	**1.33**	**0.31**	**0.64**	**0.12**	0.08	**-0.30**	**-0.79**	**-0.65**	**-0.14**	-0.01	**-0.46**
othr	1.70	**-0.54**	**-0.20**	**0.44**	0.15	**-0.18**	**-0.32**	-0.10	0.19	**0.24**	**0.27**	**-0.63**	0.01	0.01	**0.08**	**-0.38**	**-0.29**
mort	-2.21	**0.25**	0.22	-0.01	**-0.66**	-0.01	**2.13**	**0.40**	**0.70**	0.07	**-0.44**	**-0.74**	-0.05	**-1.34**	**0.03**	**1.12**	**0.55**
nrg	11.68	**-1.29**	**-5.61**	**5.58**	**2.16**	**-3.24**	-2.07	**1.38**	-0.81	0.65	**-3.86**	**-1.44**	0.90	0.26	**-0.09**	**-6.81**	2.59
rec	**2.49**	**-0.02**	**-0.37**	**-2.12**	**1.01**	**-0.62**	**0.40**	**-0.45**	**-1.10**	0.02	**1.03**	0.01	**-0.30**	**0.69**	**-0.44**	**0.49**	**-0.27**
trans	0.31	**0.08**	**-0.39**	**-0.98**	**0.32**	-0.06	0.06	-0.03	0.27	**0.15**	**0.21**	**-0.38**	**-0.32**	**0.42**	**0.20**	**-0.38**	**0.29**

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.9: QUAIDS model with regional predictors, uncompensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-1.09**	**0.16**	**0.28**	0.09	**-0.23**	0.04	-0.06	**-0.28**	**-0.36**	0.02	0.01	0.02	**0.32**	**-0.17**	**0.12**	**0.25**	-0.12
air	2.02	**-1.17**	**2.16**	**-0.93**	**-1.34**	**0.75**	**-2.15**	**-1.89**	0.61	**-0.41**	**-0.84**	**-0.39**	**-1.32**	0.73	**0.10**	**3.49**	-0.41
alc	2.21	**1.40**	**-0.15**	-0.01	**0.57**	**-0.87**	**-1.09**	**-0.71**	-0.04	**0.40**	**0.89**	**0.31**	-0.35	0.66	**-0.68**	**-2.56**	**-0.98**
cloth	0.78	**-0.65**	-0.01	**-0.89**	**0.64**	**0.67**	**-0.75**	**0.92**	-0.11	-0.03	**2.13**	0.01	-0.07	**1.03**	**-0.35**	**-3.71**	**-0.60**
comm	-1.33	**-0.62**	**0.41**	**0.43**	**-1.05**	**0.38**	**-0.47**	**0.06**	**0.49**	**0.16**	**-0.85**	-0.11	0.14	**-0.31**	**0.27**	**0.80**	**0.63**
cont	0.20	**0.32**	**-0.58**	**0.41**	**0.36**	**-2.86**	**0.72**	**0.59**	-0.27	**0.26**	-0.09	**0.70**	**-0.69**	0.40	**0.10**	-0.35	-0.23
take	-0.33	**-0.95**	**-0.74**	**-0.47**	**-0.45**	**0.74**	**-1.03**	**-0.32**	**1.24**	-0.07	**0.58**	**0.22**	-0.20	0.19	**-0.20**	**1.04**	-0.25
educ	-5.92	**-3.22**	**-1.86**	**2.23**	0.22	**2.30**	**-1.22**	**4.25**	**3.12**	**-0.49**	-0.77	**2.23**	-0.60	**1.05**	**0.40**	**-3.67**	0.95
elec	-1.61	0.22	-0.02	-0.06	**0.38**	-0.23	**1.02**	**0.66**	**-1.90**	0.19	0.23	-0.01	0.58	**-1.05**	0.05	0.06	0.49
food	0.03	**-0.05**	**0.08**	-0.01	0.04	**0.07**	-0.02	-0.04	0.06	**-0.91**	**-0.11**	**-0.04**	-0.09	0.02	0.01	-0.01	-0.03
hlth	0.10	**-0.56**	**0.92**	**2.03**	**-1.23**	-0.14	**0.88**	**-0.30**	0.41	**-0.62**	**-5.52**	**-1.13**	**0.68**	**0.75**	**-0.16**	**2.21**	**0.68**
insur	0.09	**-0.14**	**0.16**	0.01	-0.08	**0.56**	**0.17**	**0.45**	-0.01	-0.11	**-0.58**	**-0.75**	**-0.52**	0.06	**-0.05**	-0.13	-0.13
othr	1.03	**-0.34**	**-0.14**	**-0.03**	0.08	**-0.42**	**-0.12**	-0.09	**0.42**	**-0.20**	**0.27**	**-0.39**	**-0.84**	0.17	**0.12**	-0.11	**-0.41**
mort	-0.52	**0.24**	**0.29**	**0.47**	**-0.21**	**0.25**	0.08	**0.23**	**-0.86**	-0.08	**0.33**	0.00	0.11	**-0.82**	**-0.21**	-0.25	**-0.48**
nrg	4.37	0.30	**-3.09**	**-1.46**	**1.68**	0.66	-1.31	**0.69**	0.37	0.16	-0.71	-0.43	1.30	-1.83	**-1.00**	-1.82	1.10
rec	0.61	**0.69**	**-0.78**	**-1.05**	**0.34**	**-0.16**	**0.47**	**-0.42**	0.03	-0.01	**0.65**	**-0.08**	-0.08	-0.07	**-0.12**	**-1.13**	**0.11**
trans	-0.37	**-0.10**	**-0.37**	**-0.21**	**0.33**	**-0.13**	**-0.14**	**0.14**	0.33	-0.06	**0.25**	**-0.09**	**-0.38**	-0.24	**0.09**	0.14	**-0.19**

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.10: QUAIDS model with regional predictors, compensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-0.91**	**0.18**	**0.30**	**0.11**	**-0.20**	0.07	-0.03	**-0.27**	**-0.32**	**0.13**	0.03	0.06	**0.38**	**-0.13**	**0.13**	**0.32**	-0.07
air	2.48	**-1.13**	**2.22**	**-0.87**	**-1.26**	**0.83**	**-2.06**	**-1.87**	0.71	-0.11	**-0.78**	-0.28	-1.18	**0.84**	**0.11**	**3.68**	-0.26
alc	2.47	**1.42**	**-0.12**	0.02	**0.62**	**-0.82**	**-1.04**	**-0.70**	0.01	**0.57**	**0.92**	**0.37**	-0.27	**0.72**	**-0.67**	**-2.46**	**-0.89**
cloth	1.13	**-0.62**	0.03	**-0.85**	**0.71**	**0.74**	**-0.68**	**0.93**	-0.03	**0.20**	**2.17**	0.10	0.04	**1.11**	**-0.34**	**-3.57**	-0.48
comm	-1.21	**-0.61**	**0.42**	**0.44**	**-1.03**	**0.40**	**-0.45**	**0.07**	**0.51**	**0.24**	**-0.84**	-0.08	0.17	**-0.29**	**0.27**	**0.85**	**0.67**
cont	0.50	**0.35**	**-0.54**	**0.45**	**0.41**	**-2.80**	**0.78**	**0.60**	-0.20	**0.45**	-0.05	**0.77**	**-0.60**	**0.47**	**0.10**	-0.22	-0.13
take	-0.01	**-0.92**	**-0.70**	**-0.43**	**-0.39**	**0.80**	**-0.98**	**-0.30**	**1.31**	0.13	**0.62**	**0.29**	-0.11	0.27	**-0.19**	**1.17**	-0.15
educ	-5.71	**-3.20**	**-1.83**	**2.25**	0.26	**2.34**	**-1.18**	**4.26**	**3.17**	-0.36	-0.74	**2.28**	-0.54	**1.10**	**0.41**	**-3.58**	1.03
elec	-1.52	0.23	-0.01	-0.05	**0.39**	-0.21	**1.03**	**0.67**	**-1.88**	0.24	0.24	0.01	0.61	**-1.04**	0.05	0.10	0.52
food	0.16	**-0.04**	**0.09**	0.01	**0.06**	**0.10**	0.00	-0.03	0.09	**-0.83**	**-0.10**	-0.01	-0.05	0.05	0.01	0.05	0.01
hlth	0.40	**-0.53**	**0.95**	**2.06**	**-1.17**	-0.08	**0.94**	**-0.29**	0.48	**-0.42**	**-5.49**	**-1.06**	**0.78**	**0.82**	**-0.15**	**2.33**	**0.78**
insur	0.35	**-0.11**	**0.20**	0.04	-0.04	**0.60**	**0.22**	**0.46**	0.05	0.06	**-0.55**	**-0.69**	**-0.43**	0.12	**-0.04**	-0.03	-0.04
othr	1.36	**-0.32**	**-0.10**	0.01	**0.13**	**-0.36**	-0.06	-0.08	**0.49**	0.01	**0.30**	**-0.31**	**-0.74**	0.25	**0.12**	0.02	**-0.30**
mort	-0.20	**0.27**	**0.33**	**0.51**	**-0.16**	**0.31**	0.13	**0.25**	**-0.79**	0.13	**0.37**	0.08	0.21	**-0.74**	**-0.20**	-0.12	-0.37
nrg	4.57	0.32	**-3.06**	**-1.44**	**1.72**	0.69	-1.28	**0.70**	0.42	0.29	-0.69	-0.38	1.37	**-1.78**	**-0.99**	-1.74	1.17
rec	0.93	**0.71**	**-0.74**	**-1.01**	**0.40**	**-0.10**	**0.52**	**-0.41**	0.11	**0.20**	**0.69**	0.00	0.02	0.00	**-0.11**	**-1.00**	**0.22**
trans	-0.20	**-0.09**	**-0.34**	**-0.19**	**0.36**	**-0.09**	**-0.11**	**0.14**	**0.36**	0.05	**0.27**	**-0.05**	**-0.32**	-0.20	**0.10**	0.21	**-0.13**

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.11: QUAIDS model with household size predictors, uncompensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-0.54**	**0.18**	**0.24**	**-0.19**	**-0.09**	**0.16**	**-0.20**	**-0.25**	**-0.08**	**-0.10**	**-0.10**	0.01	0.11	**-0.20**	**0.20**	0.05	**-0.20**
air	2.22	**-0.88**	**1.92**	**-1.27**	**-1.31**	**1.59**	**-1.68**	**-2.00**	-0.08	-0.43	**-1.11**	**-0.25**	**-1.37**	**0.68**	**-0.10**	**3.17**	-0.13
alc	1.91	**1.27**	**0.18**	**0.36**	**0.73**	**-1.12**	**-0.64**	**-1.01**	-0.34	**0.59**	**2.31**	0.03	-0.40	**0.67**	**-1.43**	**-3.13**	**-0.98**
cloth	-1.64	**-0.90**	**0.39**	**-1.24**	**0.78**	**0.30**	**-0.60**	**1.29**	0.00	0.11	**3.31**	**0.25**	0.53	**0.68**	**0.08**	**-3.45**	**-0.88**
comm	-0.51	**-0.62**	**0.53**	**0.52**	**-0.92**	0.15	**-0.90**	**-0.05**	**0.87**	0.03	**-0.69**	**-0.25**	-0.14	**-0.36**	**0.18**	**0.71**	**0.46**
cont	0.89	**0.70**	**-0.75**	**0.18**	0.14	**-2.33**	**1.20**	**0.40**	**-0.98**	0.23	**-0.82**	**0.69**	**-0.57**	**0.80**	**-0.32**	**-0.66**	0.19
take	-1.08	**-0.75**	**-0.43**	**-0.38**	**-0.84**	**1.21**	**-1.15**	**-0.47**	**1.04**	0.07	**-0.66**	**0.20**	0.07	0.22	**-0.06**	**1.89**	0.11
educ	-5.23	**-3.41**	**-2.60**	**3.09**	-0.17	**1.56**	**-1.79**	**4.96**	**3.46**	-0.20	**-2.99**	**2.61**	-0.97	**1.44**	**1.35**	**-2.91**	0.79
elec	-0.40	-0.03	-0.21	0.00	**0.73**	**-0.89**	**0.93**	**0.81**	**-1.21**	**0.16**	**0.62**	-0.11	-0.01	**-0.87**	0.02	-0.62	0.07
food	-0.15	**-0.05**	**0.11**	**0.02**	0.01	**0.07**	0.02	-0.01	0.05	**-0.98**	**-0.08**	0.01	-0.02	-0.03	0.00	0.07	-0.02
hlth	-0.88	**-0.76**	**2.38**	**3.17**	**-1.00**	**-1.27**	**-1.01**	**-1.20**	**1.07**	-0.44	**-3.78**	**-1.61**	**1.10**	0.10	**-0.10**	**2.72**	**0.48**
insur	0.04	**-0.09**	0.02	**0.12**	**-0.19**	**0.56**	**0.16**	**0.54**	-0.09	0.01	**-0.84**	**-0.68**	**-0.50**	**0.21**	**-0.09**	-0.16	-0.03
othr	0.34	**-0.36**	**-0.16**	**0.20**	-0.08	**-0.34**	0.04	**-0.15**	-0.01	-0.04	**0.43**	**-0.37**	**-0.48**	0.07	**0.07**	**0.21**	**-0.36**
mort	-0.92	**0.25**	**0.32**	**0.32**	**-0.29**	**0.60**	0.14	**0.30**	**-0.77**	**-0.23**	0.03	**0.17**	0.03	**-0.65**	**-0.24**	-0.30	**-0.38**
nrg	6.14	**-0.24**	**-5.36**	0.29	**0.93**	**-1.81**	-0.35	**1.96**	0.13	0.05	-0.36	**-0.64**	0.61	**-1.67**	**-0.11**	-0.45	-0.12
rec	0.11	**0.64**	**-0.96**	**-0.98**	**0.30**	**-0.30**	**0.86**	**-0.34**	**-0.31**	0.11	**0.81**	**-0.09**	0.16	**-0.14**	**-0.04**	**-0.98**	**0.16**
trans	-0.59	-0.03	**-0.37**	**-0.31**	**0.24**	**0.11**	**0.06**	**0.12**	0.04	-0.04	**0.18**	-0.02	**-0.34**	-0.19	-0.01	**0.19**	-0.03

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Table C.12: QUAIDS model with household size predictors, compensated price elasticities

	Price:																
Quantity:	accom	air	alc	cloth	comm	cont	take	educ	elec	food	hlth	insur	othr	mort	nrg	rec	trans
accom	**-0.36**	**0.20**	**0.26**	**-0.17**	**-0.06**	**0.20**	**-0.16**	**-0.24**	-0.05	0.02	**-0.08**	0.05	0.16	**-0.16**	**0.21**	0.12	**-0.14**
air	2.68	**-0.84**	**1.98**	**-1.22**	**-1.23**	**1.67**	**-1.59**	**-1.98**	0.02	-0.13	**-1.05**	-0.14	**-1.23**	**0.79**	**-0.08**	**3.36**	0.03
alc	2.13	**1.29**	**0.21**	**0.39**	**0.77**	**-1.08**	**-0.60**	**-1.00**	-0.30	**0.74**	**2.34**	0.08	-0.33	**0.72**	**-1.42**	**-3.04**	**-0.91**
cloth	-1.27	**-0.87**	**0.44**	**-1.20**	**0.84**	**0.37**	**-0.53**	**1.31**	0.07	**0.35**	**3.35**	**0.34**	0.64	**0.77**	**0.10**	**-3.31**	**-0.76**
comm	-0.39	**-0.61**	**0.54**	**0.54**	**-0.90**	0.17	**-0.88**	**-0.04**	**0.90**	**0.11**	**-0.68**	**-0.23**	-0.11	**-0.33**	**0.18**	**0.75**	**0.50**
cont	1.18	**0.72**	**-0.71**	**0.22**	**0.19**	**-2.28**	**1.25**	**0.42**	**-0.92**	**0.42**	**-0.79**	**0.76**	**-0.48**	**0.87**	**-0.31**	**-0.54**	**0.29**
take	-0.78	**-0.72**	**-0.39**	**-0.34**	**-0.79**	**1.26**	**-1.10**	**-0.45**	**1.11**	**0.27**	**-0.62**	**0.27**	0.16	**0.29**	**-0.05**	**2.01**	0.21
educ	-4.96	**-3.39**	**-2.57**	**3.12**	-0.13	**1.61**	**-1.74**	**4.98**	**3.51**	-0.02	**-2.96**	**2.67**	-0.89	**1.50**	**1.36**	**-2.80**	0.88
elec	-0.32	-0.02	-0.20	0.01	**0.74**	**-0.87**	**0.95**	**0.81**	**-1.19**	**0.21**	**0.63**	-0.09	0.01	**-0.85**	0.02	-0.59	0.10
food	-0.02	**-0.04**	**0.13**	**0.03**	0.03	**0.09**	**0.05**	-0.01	0.08	**-0.90**	**-0.06**	**0.04**	0.02	0.00	0.01	0.12	0.02
hlth	-0.59	**-0.73**	**2.42**	**3.21**	**-0.95**	**-1.22**	**-0.96**	**-1.18**	**1.13**	-0.25	**-3.74**	**-1.55**	**1.19**	0.16	**-0.09**	**2.84**	**0.58**
insur	0.30	**-0.07**	0.05	**0.15**	**-0.14**	**0.61**	**0.20**	**0.56**	-0.04	**0.18**	**-0.81**	**-0.62**	**-0.42**	**0.27**	**-0.08**	-0.06	0.06
othr	0.67	**-0.33**	**-0.12**	**0.23**	-0.02	**-0.28**	**0.10**	**-0.13**	0.06	0.17	**0.46**	**-0.30**	**-0.38**	0.15	**0.08**	**0.34**	**-0.26**
mort	-0.56	**0.28**	**0.36**	**0.36**	**-0.23**	**0.67**	**0.21**	**0.32**	**-0.69**	0.00	0.07	**0.25**	0.15	**-0.56**	**-0.22**	-0.15	-0.26
nrg	6.34	-0.22	**-5.33**	0.32	**0.96**	**-1.77**	-0.32	**1.97**	0.17	0.18	-0.34	-0.59	0.68	**-1.62**	**-0.10**	-0.37	-0.05
rec	0.43	**0.67**	**-0.92**	**-0.94**	**0.35**	**-0.24**	**0.92**	**-0.33**	**-0.25**	**0.31**	**0.84**	**-0.02**	**0.26**	-0.06	**-0.03**	**-0.85**	**0.26**
trans	-0.44	-0.02	**-0.35**	**-0.29**	**0.27**	**0.14**	**0.09**	**0.12**	0.08	0.06	**0.19**	**0.02**	**-0.29**	-0.15	-0.01	**0.25**	0.02

accom = Accommodation, air = Air transport, alc = Alcohol and tobacco, cloth = Clothing, comm = Communications, cont = Household contents, take = Takeaways and eating out, educ = Education, elec = Electricity, food = Groceries, hlth = Health, insur = Insurance, othr = Miscellaneous, mort = Mortgage interest, nrg = Energy excluding electricity, rec = Recreation, trans = Transport.

Values in bold have p-values less than 0.05.

Appendix D

Effects of high fixed charges

Table D.1: Baseline Atkinson indices of equivalised real disposable income by year

	Year				
Household	2007	2010	2013	2016	2019
Single - no children	0.14	0.13	0.10	0.15	0.15
65+ single	0.09	0.07	0.10	0.08	0.08
Single - 1 child	0.09	0.08	0.10	0.07	0.06
Single - 2 children	0.05	0.16	0.07	0.12	0.08
Single - 3+ children	0.04	0.06	0.09	0.07	0.12
65+ couple	0.11	0.16	0.10	0.12	0.15
Couple - no children	0.10	0.08	0.12	0.11	0.11
Couple - 1 child	0.08	0.08	0.09	0.09	0.08
Couple - 2 children	0.08	0.08	0.11	0.07	0.09
Couple - 3+ children	0.07	0.09	0.12	0.09	0.14
3 adults - no children	0.07	0.08	0.06	0.07	0.09
3+ adults - 1+ children	0.08	0.07	0.08	0.09	0.09
4+ adults - no children	0.08	0.08	0.08	0.07	0.07
Total	0.11	0.11	0.12	0.11	0.13

$\epsilon = 0.60$

Table D.2: Baseline Atkinson indices of unequivalised real disposable income

	Inequality aversion ϵ			
Household	0.2	0.5	0.6	0.9
Single - no children	0.04	0.11	0.13	0.20
65+ single	0.03	0.07	0.08	0.12
Single - 1 child	0.03	0.07	0.08	0.13
Single - 2 children	0.03	0.08	0.09	0.14
Single - 3+ children	0.03	0.07	0.08	0.12
65+ couple	0.05	0.11	0.13	0.18
Couple - no children	0.03	0.09	0.10	0.15
Couple - 1 child	0.03	0.07	0.09	0.13
Couple - 2 children	0.03	0.07	0.08	0.12
Couple - 3+ children	0.03	0.08	0.10	0.15
3 adults - no children	0.02	0.06	0.07	0.11
3+ adults - 1+ children	0.03	0.07	0.08	0.12
4+ adults - no children	0.03	0.06	0.08	0.11
Total	0.05	0.12	0.14	0.21

Weighted average for 2007, 2010, 2013, 2016, 2019

Table D.3: Aggregate compensating variation by year, QUAIDS model, 2017 dollar millions

	Year:					
Household	2007	2010	2013	2016	2019	Total
Single - no children	4.8	-0.9	-0.2	-1.5	5.0	7.1
65+ single	-3.6	-5.5	-1.5	-4.4	-1.8	-16.8
Single - 1 child	-0.3	1.8	-0.1	0.5	1.0	3.0
Single - 2 children	1.5	1.2	-0.3	1.8	0.3	4.4
Single - 3+ children	0.3	2.6	-0.5	0.1	0.9	3.3
65+ couple	9.4	2.8	7.6	8.2	4.5	32.5
Couple - no children	42.3	48.5	21.2	34.4	38.2	184.6
Couple - 1 child	16.6	24.1	9.7	15.3	11.9	77.7
Couple - 2 children	18.5	31.7	29.4	31.3	22.1	133.1
Couple - 3+ children	15.1	12.2	12.9	3.5	10.8	54.4
3 adults - no children	18.3	24.1	15.6	28.7	17.6	104.3
3+ adults - 1+ children	31.0	15.2	24.7	22.3	27.1	120.3
4+ adults - no children	10.4	10.8	12.8	12.5	18.8	65.3
Total	164	169	131	153	156	773.2

Population weighted sum 2007, 2010, 2013, 2016, 2019.

Income quintile ordered from lowest to highest.

Sign of CV reversed. Positive values represent welfare gains.

Table D.4: Aggregate compensating variation by year, AIDS model, 2017 dollar millions

	Year:					
Household	2007	2010	2013	2016	2019	Total
Single - no children	-2.5	-4.6	-4.0	-5.1	-2.3	-18.5
65+ single	-4.2	-6.7	-4.8	-5.5	-5.2	-26.3
Single - 1 child	-1.8	-0.6	-2.2	-0.5	-0.7	-5.8
Single - 2 children	0.3	0.1	-0.8	0.8	-0.6	-0.2
Single - 3+ children	-0.2	0.4	-0.5	-0.1	0.0	-0.4
65+ couple	1.0	-2.5	-0.4	1.6	-2.2	-2.6
Couple - no children	12.7	17.6	2.7	13.7	12.1	58.9
Couple - 1 child	4.9	7.4	2.2	6.3	4.6	25.4
Couple - 2 children	6.8	13.2	12.2	10.8	7.8	50.9
Couple - 3+ children	4.9	4.4	3.6	0.1	2.7	15.7
3 adults - no children	7.0	9.0	3.7	11.7	6.5	38.0
3+ adults - 1+ children	11.1	4.4	10.0	8.3	9.2	43.0
4+ adults - no children	3.7	3.3	4.3	4.4	6.1	21.7
Total	44	46	26	47	38	199.8

Population weighted sum 2007, 2010, 2013, 2016, 2019.

Income quintile ordered from lowest to highest.

Sign of CV reversed. Positive values represent welfare gains.

Table D.5: Mean compensating variation per household, QUAIDS model, 2017 dollars

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-36	-14	-6	19	86	8
65+ single	-45	-33	-27	-33	23	-23
Single - 1 child	-2	-11	4	14	83	16
Single - 2 children	15	2	33	17	148	37
Single - 3+ children	19	-12	4	169	49	45
65+ couple	-22	-6	13	58	185	43
Couple - no children	18	68	118	140	272	117
Couple - 1 child	41	83	78	122	293	121
Couple - 2 children	74	170	178	215	329	188
Couple - 3+ children	79	141	75	181	308	151
3 adults - no children	85	78	110	305	313	174
3+ adults - 1+ children	96	199	212	178	464	230
4+ adults - no children	122	265	378	108	237	219
Total	27	72	90	117	235	108

Population weighted means 2007, 2010, 2013, 2016, 2019.

Income quintile ordered from lowest to highest.

Sign of CV reversed. Positive values represent welfare gains.

Table D.6: Mean compensating variation per household, AIDS model, 2017 dollars

	Disposable income quintile:					
Household	1	2	3	4	5	Total
Single - no children	-51	-30	-29	-23	25	-23
65+ single	-56	-37	-36	-49	-8	-37
Single - 1 child	-79	-27	-45	-30	22	-34
Single - 2 children	-19	-12	-24	-40	101	-4
Single - 3+ children	-26	-55	-18	60	-3	-9
65+ couple	-54	-40	-24	3	97	-5
Couple - no children	-23	4	35	70	182	49
Couple - 1 child	-12	22	33	52	215	60
Couple - 2 children	22	76	86	129	282	114
Couple - 3+ children	0	48	39	97	221	75
3 adults - no children	10	0	52	225	223	98
3+ adults - 1+ children	20	107	109	100	417	152
4+ adults - no children	34	155	259	59	149	129
Total	-19	15	31	55	165	49

Population weighted means 2007, 2010, 2013, 2016, 2019.

Income quintile ordered from lowest to highest.

Sign of CV reversed. Positive values represent welfare gains.

Table D.7: Percentage change in Atkinson index of equivalised income by year, QUAIDS model

Household	Year 2007	2010	2013	2016	2019
Single - no children	-1.08	0.83	0.30	0.36	-0.06
65+ single	0.78	-10.97	0.51	0.65	-9.01
Single - 1 child	-0.12	0.73	0.03	0.39	0.23
Single - 2 children	2.68	-0.13	0.57	0.73	-9.09
Single - 3+ children	-0.02	0.02	0.79	0.05	0.03
65+ couple	0.92	0.19	-3.79	0.28	0.36
Couple - no children	-0.08	0.30	-0.45	0.16	0.18
Couple - 1 child	0.45	-0.59	-1.91	0.13	0.36
Couple - 2 children	0.51	-0.25	-1.42	0.37	-0.08
Couple - 3+ children	-0.29	0.15	-0.40	-0.31	-0.46
3 adults - no children	-0.68	-1.16	1.05	-0.02	-0.03
3+ adults - 1+ children	-0.35	0.31	0.78	0.31	-0.29
4+ adults - no children	-0.19	1.78	-0.58	-0.04	-0.25
Total	0.02	-0.32	-0.33	0.31	-0.44

$\epsilon = 0.60$

Table D.8: Percentage change in Atkinson index of equivalised income by year, AIDS model

	Year				
Household	2007	2010	2013	2016	2019
Single - no children	-0.74	0.83	0.28	0.35	0.33
65+ single	0.72	-10.12	0.47	0.65	-8.91
Single - 1 child	1.03	0.82	0.52	0.55	0.78
Single - 2 children	2.31	0.14	1.49	0.66	-3.54
Single - 3+ children	-0.18	0.30	0.82	0.15	0.58
65+ couple	0.66	0.30	-3.67	0.30	0.47
Couple - no children	0.15	0.45	-0.43	0.23	0.23
Couple - 1 child	0.39	-0.28	-1.89	0.21	0.49
Couple - 2 children	0.68	-0.07	-1.35	0.64	-0.03
Couple - 3+ children	0.11	0.33	-0.03	0.00	0.25
3 adults - no children	-0.66	-1.04	1.06	0.23	0.13
3+ adults - 1+ children	-0.08	0.40	0.91	0.30	-0.08
4+ adults - no children	-0.04	1.94	-0.22	-0.09	-0.06
Total	0.15	-0.19	-0.25	0.36	-0.23

$\epsilon = 0.60$

Table D.9: Percentage change in Atkinson index by year, income measure, and model

	Year:					
Income:	2007	2010	2013	2016	2019	Average
			QUAIDS model			
Equivalised	0.020	-0.325	-0.328	0.307	-0.440	-0.167
Unequivalised	0.04	-0.29	-0.17	0.31	-0.34	-0.10
			AIDS model			
Equivalised	0.15	-0.19	-0.25	0.36	-0.23	-0.04
Unequivalised	0.15	-0.18	-0.11	0.35	-0.17	0.00

$\epsilon = 0.60$

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